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Priority Surface

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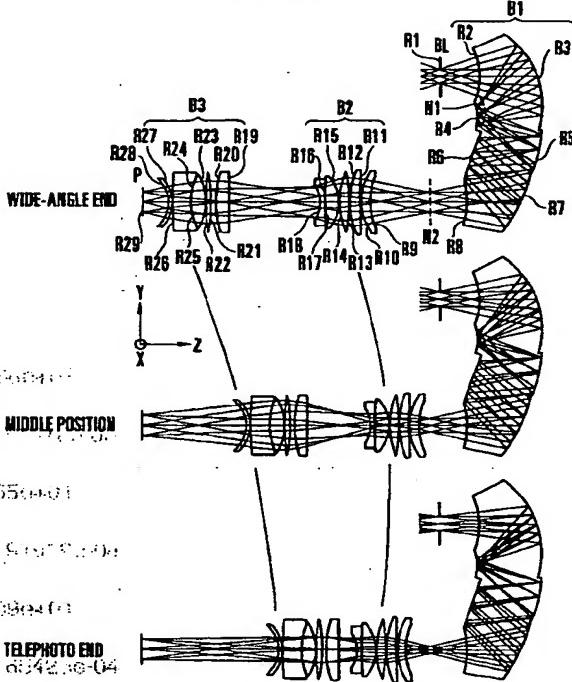
(54) Zoom lens

(57) A zoom optical system comprises a plurality of optical elements. The plurality of optical elements include a first optical element having two refracting surfaces and a plurality of reflecting surfaces formed in a transparent body, being arranged such that a light beam enters an inside of the transparent body from one of the two refracting surfaces and, after being successively reflected from the plurality of reflecting surfaces, exits from the other of the two refracting surfaces, and/or a second optical element having a plurality of surface mirrors integrally formed and decentered relative to one another, being arranged such that an incident light beam exits therefrom after being successively reflected from reflecting surfaces of the plurality of surface mirrors, and a third optical element composed of a plurality of coaxial refracting surfaces. In the zoom optical system, an image of an object is formed through the plurality of optical elements, and zooming is effected by varying relative positions of at least two optical elements of the plurality of optical elements.

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FIG. 1



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B5

R=+1.27056e+01

Lens 4 40538e 05

Lens 2 22752e 03

R=-2.36243e+01

Lens 4 24795e 06

Lens 1 96579e 04

R=+1.98259e+01

Lens 1 6342.3e 04

TELEPHOTO END

B6

R=-3.1731e+00

Lens 4 6301.8e 05

Lens 4 63227e 03

R=-1.60643e+01

Lens 4 69945e 04

Lens 4 63387e 03

R=+1.72831e+01

Lens 4 63913e 02

Description**BACKGROUND OF THE INVENTION****5 Field of the Invention**

This invention relates to zoom optical systems and image pickup apparatus using the same and, more particularly, to an optical system which comprises a plurality of optical elements of two types, one of which has a plurality of reflecting surfaces and the other of which has refracting surfaces alone, wherein, of the plurality of optical elements, at least 10 two optical elements move in differential relation to effect zooming (to vary magnification). Still more particularly, this invention relates to zoom optical systems suited to be used in video cameras, still video cameras or copying machines.

Description of Related Art

15 The zoom optical systems for the image pickup apparatus have been known as constructed with refracting elements or lenses alone. These lenses are of the spherical or aspheric form of revolution symmetry and arranged on a common optical axis so that their surfaces take revolution symmetry with respect to the optical axis.

In the field of art of photographic objectives, there have been many previous proposals for utilizing reflecting surfaces such as convex or concave mirrors. It has been also known to provide an optical system which makes use of a reflecting system and a refracting system in conjunction. This optical system is well known as the catadioptric system.

20 Fig. 23 is a schematic diagram of an optical system composed of one concave mirror and one convex mirror, or so-called mirror optical system.

25 In the mirror optical system shown in Fig. 23, an axial light beam 104 coming from an object is reflected by the concave mirror 101. While being converged, the light beam 104 goes toward the object side. After having been reflected by the convex mirror 102, the light beam 104 forms an image on an image plane 103.

This mirror optical system is based on the configuration of the Cassegrain type of reflecting telescope. The aim of adopting it is to shorten the total length of the entire optical system compared with the long physical length of the refracting telescope, as the optical path is folded by using two reflecting mirrors as arranged in opposed relation.

Even for the objective lens system constituting part of the telescope, for the same reason, the Cassegrain type and 30 many other types have come to be known which differ in the number and the construction and arrangement of reflecting mirrors in order to ever more shorten the total length of the entire system.

Up to now, effort has been made to shorten the total length of the photographic lens as it is usually unduly long. For this purpose, instead of some of its lens elements, mirrors are used to efficiently fold up the optical path. A compact optical system of mirror type is thus obtained.

35 In the Cassegrain type reflecting telescopes or like mirror optical systems, however, the use of the convex mirror 102 leads, in general case, to a problem that the object light beam 104 is shaded in part. This is attributable to the fact that the back of the convex mirror 102 lies within the domain of passage of the object light beam 104.

To solve this problem, the mirror may be decentered, thus permitting the domain of passage of the object light beam 104 to be cleared of the obstruction of the other parts of the optical system. In other words, the principal ray 106 of the 40 object light beam 104 is set off from an optical axis 105. Such a mirror optical system, too, has previously been proposed.

Fig. 24 is a schematic diagram of a mirror optical system disclosed in U.S. Patent No. 3,674,334, which has solved the above-described problem of shading in such a way that the mirrors of revolution symmetry with respect to the optical axis are cut off in part.

45 The mirror optical system shown in Fig. 25 comprises, in the order in which the light beam encounters, a concave mirror 111, a convex mirror 113 and a concave mirror 112. In the prototype design, these are of the forms shown by the double-dots and single-dash lines, or of revolution symmetry with respect to the optical axis 114. In actual practice, the concave mirror 111 is used in only the upper half on the paper of the optical axis 114, the convex mirror 113 in only the lower half and the concave mirror 112 in only a lower marginal portion, thereby bringing a principal ray 116 of the object light beam 115 away from the optical axis 114. The optical system is thus made free from the shading of the object light beam 115.

Fig. 25 is a schematic diagram of another mirror optical system disclosed in U.S. Patent No. 5,063,586. In this mirror optical system, the mirrors are so arranged that their central axes set themselves off the optical axis of the system. By this arrangement, a principal ray of the object light beam is dislocated from the optical axis, thus solving the above-described problem.

55 In Fig. 25, an object to be photographed lies in a plane 121. Assuming that a line perpendicular to the plane 121 is an optical axis 127, it is found that, as the light beam encounters a convex mirror 122, a concave mirror 123, a convex mirror 124 and a concave mirror 125 successively in this order, the centers of area of their reflecting surfaces and their central axes (the lines connecting those centers with the respective centers of curvature of these reflecting surfaces)

122a, 123a, 124a and 125a are decentered from the optical axis 127. In Fig. 25, the amounts of decentering of such parameters and the radii of curvature of all the surfaces are appropriately determined to prevent the object light beam 128 from being shaded by the back of any one of the mirrors. An object image is thus formed on a focal plane 126 with high efficiency.

5 In addition, U.S. Patents Nos. 4,737,021 and 4,265,510 even disclose similar systems freed from the shading effect either by using partial mirrors of revolution symmetry with respect to the optical axis or by arranging the central axes themselves of the mirrors in decentered relation from the optical axis. It is also known where the mirror optical system is an 10 Meanwhile, the catadioptric optical system using both reflecting mirrors and refracting lenses can be made to have the function of varying the image magnification. As an example of this optical system, mention may be made of deep sky telescopes disclosed in, for example, U.S. Patents Nos. 4,477,156 and 4,571,036, in which the image magnification is made variable by using a parabolic mirror in the main mirror in conjunction with the Erle eye-piece. It is also known to provide another zooming technique which moves two mirrors constituting part of the above-described mirror optical system in differential relation. By this technique, the image magnification (or focal length) of the optical system for photography is made variable.

15 For example, U.S. Patent No. 4,812,030 discloses application of such a zooming technique to the Cassegrain type reflecting telescope shown in Fig. 23, wherein the separation from the concave mirror 101 to the convex mirror 102 and the separation from the convex mirror 102 to the image plane 103 are made variable relative to each other. Thus, a mirror optical system for photography capable of zooming is obtained.

Fig. 26 shows another example of application disclosed in the above U.S. Patent No. 4,812,030. Referring to Fig.

20 26, a light beam 138 from an object encounters a first concave mirror 131 and is reflected from its surface, becoming a converging light beam. The converging light beam goes toward the object side, and encounters a first convex mirror 132. Here, the light beam is reflected toward the image side, becoming an almost parallel light beam. The almost parallel light beam goes to a second convex mirror 134 and is reflected therefrom, becoming a diverging light beam. The diverging light beam encounters a concave mirror 135. Here, the light beam is reflected and becomes a converging light beam, focusing an image on an image plane 137.

In this optical system, the separation between the first concave mirror 131 and the first convex mirror 132 is made to vary, while the separation between the second convex mirror 134 and the second concave mirror 135 is made to vary simultaneously, so as to effect zooming. The focal length of the entirety of the mirror optical system is thus made variable.

25 30 Also, in U.S. Patent No. 4,993,818, an image formed by the Cassegrain reflecting telescope shown in Fig. 23 is then re-focused by another mirror optical system provided in the rear stage, thereby forming a secondary image. The magnifying power of the mirror optical system for forming the secondary image is made variable. By this arrangement, the photographic system as a whole is provided with the capability of varying the image magnification.

These reflecting optical systems for photography have a great number of constituent parts. To obtain the required 35 optical performance, it is necessary to increase the accuracy with which to set up the individual optical parts. In particular, because the positioning tolerance for the mirrors is severe, it is indispensable to adjust the position and angle of each mirror.

To solve this problem, a method has been proposed, for example, to construct the mirror system in the form of one block, thus avoiding an error from occurring when the optical parts are set up.

40 45 Heretofore, what are known as such a block having a large number of reflecting surfaces therein are, for example, optical prisms such as pentagonal roof prisms or Porro-prisms used in the viewfinder systems.

For these prisms, a plurality of reflecting surfaces are unified by the molding techniques. All these reflecting surfaces are, therefore, made up under the control of their relative positions with high accuracy, thus obviating the necessity of doing later adjustment of the relative positions of the assembled reflecting surface to one another. However, the main function of these prisms is to change the direction in which light advances for the purpose of inverting the image. Every reflecting surface has, therefore, to take the plain form.

On the other hand, there is also known an optical system in which curvature is imparted to the reflecting surface of the prism.

50 55 Fig. 27 is a schematic diagram showing the main parts of an observing optical system disclosed in U.S. Patent No. 4,775,217. This observing optical system is used for observing the external field or landscape and, at the same time, presenting an information display of data and icons in overlapping relation on the landscape.

The rays of light 145 radiating from an information display body 141 are reflected from a surface 142, going to the object side until they encounter a half-mirror 143 of concave form. After having been reflected from the half-mirror 143, the light rays 145 become nearly parallel by the refractive power of the concave surface 143, and pass through the surface 142, reaching the eye 144 of the observer. So, the observer views an enlarged virtual image of the displayed data or icons.

Meanwhile, a light beam 146 from an object enters at a surface 147 which is nearly parallel with the reflecting surface 142, and is refracted there, arriving at the concave half-mirror surface 143. Since this surface 143 is coated with a half-permeable layer by the vacuum evaporation technique, part of the light beam 146 passes through the concave sur-

face 143 and is refracted in transmitting the surface 142, entering the pupil 144 of the observer. So, the observer views the display image in overlapping relation on the external field or landscape.

Fig. 28 is a schematic diagram showing the main parts of another observing optical system disclosed in Japanese Laid-Open Patent Application No. Hei 2-297516. This observing optical system, too, is used for viewing the external field or landscape and, at the same time, looking the information on the display device as overlapping the view.

In this observing optical system, a light beam 154 from an information display body 150 enters a prism Pa at a flat surface 157 and is made incident on a parabolic reflecting surface 151. Being reflected from this surface 151, the light beam 154 converges and forms an image on a focal plane 156. During this time, the light beam 154 for display undergoes total reflection from the successive two parallel planes constituting part of the prism Pa, reaching the focal plane 156. By this arrangement, thinning of the optical system as a whole is achieved.

The display light beam 154 that has exited as a diverging beam from the focal plane 156 then proceeds while undergoing total reflection between the flat surfaces 157 and 158, until it encounters a half-mirror surface 152 of parabolic form. The light beam 154 is reflected from the half-mirror surface 152 and, at the same time, forms an enlarged virtual image of the display by its refractive power, becoming a nearly parallel beam. After having passed through the surface 157, the light beam 154 enters the pupil 153 of the observer. Thus, the observer looks at the display image on the background of the external field or landscape.

Meanwhile, an object light beam 155 from the external field passes through a flat surface 158b constituting a prism Pb, then passes through the parabolic half-mirror surface 152 and exits from the surface 157, reaching the eye 153 of the observer. So, the observer views the external field or landscape with the display image overlapping thereon.

Further, an optical element can be used on the reflecting surface of a prism. This is exemplified as an optical head for photo-pickup disclosed in, for example, Japanese Laid-Open Patent Applications Nos. Hei 5-12704 and Hei 6-139612. Such a head receives the light from a semiconductor laser, then reflects it from the Fresnel surface or hologram surface to form an image on a disk, and then conducts the reflected light from the disk to a detector.

The conventional optical system of the type which has refractive optical elements alone puts the stop inside thereof. In many cases, the entrance pupil lies deep in the optical system. The longer the separation between the stop and the entrance surface at the frontmost position, the larger the ray effective diameter of that entrance surface becomes. Further, there is a problem that, as the angle of view increases, the ray effective diameter of that entrance surface increases even more greatly.

The optical systems of the mirror type disclosed in the above U.S. Patents Nos. 3,674,334, 5,063,586 and 4,265,510 have a common feature that all the reflecting mirrors are made decentered by respective different amounts of decentering. Hence, the mounting mechanism for the reflecting mirrors becomes very elaborate in structure. It is also very difficult to secure the setup tolerance.

The photographic optical systems having the zooming function disclosed in U.S. Patents Nos. 4,812,030 and 4,993,818, too, has, in any case, a large number of constituent parts such as mirrors and lens elements for forming an image. To obtain satisfactory optical performance, therefore, it is necessary to set up all the optical parts in relation to one another with high accuracy.

Particularly for the reflecting mirrors, the tolerance for the relative position becomes severe. Therefore, it is also necessary to accurately adjust the position and orientation of each of the reflecting mirrors.

It should be also noted that the conventional reflecting type photographic optical systems are adapted for application to the so-called telephoto type of lens systems as this type has a long total length and a small field angle. To attain a photographic optical system which necessitates the field angles of from the standard lens to the wide-angle lens, because an increasing number of reflecting surfaces for correcting aberrations is required to use, the parts must be manufactured to even higher precision accuracy and assembled with even severer a tolerance. Therefore, the production cost has to be sacrificed. Otherwise, the size of the entire system tends to increase greatly.

Also, the observing optical systems disclosed in the above U.S. Patent No. 4,775,217 and Japanese Laid-Open Patent Application No. Hei 2-297516 each have an aim chiefly to produce the pupil image forming function such that, as the information display is positioned remotely of the observer's eye, the light is conducted with high efficiency to the pupil of the observer. Another chief aim is to change the direction in which light advances. Concerning the positive use of the curvature-imparted reflecting surface in correcting aberrations, therefore, no technical ideas are directly disclosed.

Also, the optical systems, for photo-pickup disclosed in the above Japanese Laid-Open Patent Applications Nos. Hei 5-12704 and Hei 6-139612 each limit its use to a detecting optical system. Therefore, these systems are unable to satisfy the imaging performance for photographic optical systems and particularly image pickup apparatus using a CCD or like area type image sensor.

BRIEF SUMMARY OF THE INVENTION

It is an object of the invention to provide a zoom optical system and an image pickup apparatus using the same, wherein there are provided a plurality of optical elements which are constituted by an optical element in which a plurality

of curved or flat reflecting surfaces are formed and an optical element composed only of coaxial refracting surfaces, and relative positions of at least two optical elements of the plurality of optical elements are varied to effect zooming, so that the zoom optical system as a whole is minimized in bulk and size, and, at the same time, the accuracy with which the reflecting surfaces are set up (or the assembling tolerance) that greatly affects the performance little differs from item to item.

Further, a stop is disposed either on the object side of the zoom optical system or adjacent to a light entrance surface at which a light beam first enters; and an object image is formed at least once within the zoom optical system. By this arrangement, despite the zoom optical system having a wide angular field, the effective diameter of every one of the optical elements is shortened. Moreover, a plurality of reflecting surfaces constituting the optical element are given appropriate refractive powers. At the same time, these reflecting surfaces are arranged in decentering relation to thereby fold the optical path in the zoom optical system to a desired shape without causing shading of a light beam within the zoom optical system. It is, therefore, another object of the invention to provide a zoom optical system of shortened total length in a certain direction and an image pickup apparatus using the same.

To attain the above objects, in accordance with one aspect of the invention, there is provided a zoom optical system, which comprises a plurality of optical elements including a first optical element having two refracting surfaces and a plurality of reflecting surfaces formed in a transparent body, being arranged such that a light beam enters an inside of the transparent body from one of the two refracting surfaces and, after being successively reflected from the plurality of reflecting surfaces, exits from the other of the two refracting surfaces, and/or a second optical element having a plurality of surface mirrors integrally formed and decentered relative to one another, being arranged such that an incident light beam exits therefrom after being successively reflected from reflecting surfaces of the plurality of surface mirrors, and a third optical element composed of a plurality of coaxial refracting surfaces, wherein an image of an object is formed through the plurality of optical elements, and zooming is effected by varying relative positions of at least two optical elements of the plurality of optical elements.

Other features, especially ones are as follows.

25 A stop is disposed on a light entrance side of the zoom optical system, or adjacent to a light entrance surface at which a light beam first enters.

30 Each of the at least two optical elements of which relative positions are varied has an entering reference axis and an exiting reference axis in parallel to each other.

35 The at least two optical elements of which relative positions are varied move on one movement plane in parallel to each other. R₁=-52.267

40 Each of the at least two optical elements of which relative positions are varied has an entering reference axis and an exiting reference axis oriented to the same direction.

45 One of the at least two optical elements of which relative positions are varied has an entering reference axis and an exiting reference axis oriented to the same direction, and another of the at least two optical elements of which relative positions are varied has an entering reference axis and an exiting reference axis oriented to opposite directions.

50 Each of the at least two optical elements of which relative positions are varied has an entering reference axis and an exiting reference axis oriented to opposite directions.

55 Focusing is effected by moving one of the at least two optical elements of which relative positions are varied.

60 Focusing is effected by moving an optical element other than the at least two optical elements of which relative positions are varied. 8.35316e-01

65 The zoom optical system forms at least once an object image at an intermediate point in an optical path thereof. Of the plurality of reflecting surfaces, curved reflecting surfaces are all formed to anamorphic shapes.

70 All reference axes of the at least two optical elements of which relative positions are varied lie on one plane.

75 At least a part of reference axes of an optical element other than the at least two optical elements of which relative positions are varied lie on the one plane. 8.35316e-01

80 At least one optical element of the plurality of optical elements has a reflecting surface in which a normal line on the reflecting surface at an intersection point of a reference axis with the reflecting surface is inclined with respect to a movement plane on which the at least two optical elements of which relative positions are varied move.

85 These and further objects and features of the invention will become apparent from the following detailed description of the preferred embodiments thereof taken in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWING

8.35316e-01 8.3532e-01 8.35376e-01

Fig. 1 shows sectional views of an embodiment 1 of the zoom optical system according to the invention with the optical paths shown in the YZ plane. 8.35352e-03 8.35374e-05

Fig. 2 shows graphs of the lateral aberrations of the embodiment 1 in the wide-angle end.

Fig. 3 shows graphs of the lateral aberrations of the embodiment 1 in a middle position.

Fig. 4 shows graphs of the lateral aberrations of the embodiment 1 in the telephoto end.

Fig. 5 is a diagram of geometry for explaining the coordinate systems in the embodiments of the invention.

- Fig. 6 shows sectional views of an embodiment 2 of the zoom optical system according to the invention with the optical paths shown in the YZ plane. Fig. 7 shows graphs of the lateral aberrations of the embodiment 2 in the wide-angle end. Fig. 8 shows graphs of the lateral aberrations of the embodiment 2 in a middle position. Fig. 9 shows graphs of the lateral aberrations of the embodiment 2 in the telephoto end.
- Fig. 10 shows sectional views of an embodiment 3 of the zoom optical system according to the invention with the optical paths shown in the YZ plane. Fig. 11 shows graphs of the lateral aberrations of the embodiment 3 in the wide-angle end. Fig. 12 shows graphs of the lateral aberrations of the embodiment 3 in a middle position. Fig. 13 shows graphs of the lateral aberrations of the embodiment 3 in the telephoto end.
- Fig. 14 shows sectional views of an embodiment 4 of the zoom optical system according to the invention with the optical paths shown in the YZ plane. Fig. 15 shows graphs of the lateral aberrations of the embodiment 4 in the wide-angle end. Fig. 16 shows graphs of the lateral aberrations of the embodiment 4 in a middle position. Fig. 17 shows graphs of the lateral aberrations of the embodiment 4 in the telephoto end.
- Fig. 18 is a perspective view of a zoom optical system with an entering reference axis taken in parallel to the X axis.
- Fig. 19 shows sectional views of an embodiment 5 of the zoom optical system according to the invention with the optical paths shown in the YZ plane.
- Fig. 20 shows graphs of the lateral aberrations of the embodiment 5 in the wide-angle end. Fig. 21 shows graphs of the lateral aberrations of the embodiment 5 in a middle position. Fig. 22 shows graphs of the lateral aberrations of the embodiment 5 in the telephoto end.
- Fig. 23 is a diagram of the basic configuration of the Cassegrain type reflecting telescope. Fig. 24 is a diagram for explaining a first method of avoiding the shading by putting the principal ray away from the optical axis in the mirror optical system. Fig. 25 is a diagram for explaining a second method of avoiding the shading by putting the principal ray away from the optical axis in the mirror optical system. Fig. 26 is a schematic diagram of the conventional zoom optical system using reflecting mirrors. Fig. 27 is a diagram of an observing optical system using a prism having its reflecting surface curved. Fig. 28 is a diagram of another observing optical system using a prism having two curved reflecting surfaces.
- Fig. 29 is a diagram of the basic design of an embodiment 6 of the zoom optical system according to the invention. Fig. 30 is a sectional view of the form of a first optical element in the embodiment 6 in a secondary image. Fig. 31 is a perspective view of the first optical element in the embodiment 6 made variable. By this arrangement, the Fig. 32 is a diagram of the basic design of an embodiment 7 of the zoom optical system according to the invention. Fig. 33 is a diagram of the basic design of an embodiment 8 of the zoom optical system according to the invention. Fig. 34 is a sectional view of the optics of the embodiment 6 in the wide-angle end. Fig. 35 is a sectional view of the optics of the embodiment 6 in a middle position. Fig. 36 is a sectional view of the optics of the embodiment 6 in the telephoto end.
- Fig. 37 shows graphs of the lateral aberrations of the embodiment 6 in the wide-angle end. Fig. 38 shows graphs of the lateral aberrations of the embodiment 6 in the middle position.
- Fig. 39 shows graphs of the lateral aberrations of the embodiment 6 in the telephoto end. Fig. 40 is a sectional view of the optics of the embodiment 7 in the wide-angle end. Fig. 41 is a sectional view of the optics of the embodiment 7 in a middle position. Fig. 42 is a sectional view of the optics of the embodiment 7 in the telephoto end.
- Fig. 43 shows graphs of the lateral aberrations of the embodiment 7 in the wide-angle end. However, the Fig. 44 shows graphs of the lateral aberrations of the embodiment 7 in the middle position. Fig. 45 shows graphs of the lateral aberrations of the embodiment 7 in the telephoto end.
- Fig. 46 is a sectional view of the optics of the embodiment 8 in the wide-angle end. Fig. 47 is a sectional view of the optics of the embodiment 8 in a middle position. Fig. 48 is a sectional view of the optics of the embodiment 8 in the telephoto end. System disclosed in U.S. Patent No. Fig. 49 shows graphs of the lateral aberrations of the embodiment 8 in the wide-angle end. And, at the same time, Fig. 50 shows graphs of the lateral aberrations of the embodiment 8 in the middle position.
- Fig. 51 shows graphs of the lateral aberrations of the embodiment 8 in the telephoto end. A surface 142, going to the object side until they encounter a half-mirror 143 of concave form. After having been reflected from the half-mirror 143, and pass through the surface 142, reaching the eye 144 of the observer. So, the observer views a enlarged virtual image of the displayed data.
- Before describing the embodiments of the invention, the way of expressing the various dimensions of the structure and the common features of all the embodiments are described below.
- Fig. 5 is a diagram taken to explain a coordinate system by which to define the design parameters for the optical system of the invention. In the embodiments of the invention, the surfaces are numbered consecutively along a ray of

light (shown by single-dot and dash lines in Fig. 5) advancing from the object side to the image plane. This ray of light will be called "reference axis ray", and the i-th surface will be expressed by R_i.

In Fig. 5, the first surface R₁ is a stop, the second surface R₂ is a refracting surface coaxial to the first surface R₁, the third surface R₃ is a reflecting surface tilted relative to the second surface R₂, the fourth surface R₄ and the fifth surface R₅ each are a reflecting surface shifted and tilted relative to the respective preceding surface, and the sixth surface R₆ is a refracting surface shifted and tilted relative to the fifth surface R₅. All of the second to sixth surfaces R₂ to R₆ are constructed on a common substrate of glass, plastic or like material to form an optical element. This is a first optical element and, in Fig. 5, indicated by B₁.

In the construction and arrangement of Fig. 5, therefore, the medium of from an object plane (not shown) to the second surface R₂ is air. The spaces between the successive two of the second surface R₂ through the sixth surface R₆ are filled with a common medium of certain material. The medium between the sixth surface R₆ and a seventh surface R₇ (not shown) is air along a line B₂ through B₃ through B₄ through B₅ through B₆ through B₇ of the system B₁ plus B₂. A light ray from the original point passes through the optical element B₁ reaching the center of area of a plane on which to form the last image. The path of this ray is defined as a reference axis of the optical system. Further, in the embodiments of the invention, the reference axis has directional factors (orientations). The orientation is taken as positive when it coincides with the direction in which the ray for the reference axis advances to the image planes refracted. Although the embodiments of the invention will be specified by reference to such an axis, it is to be noted that the choice of an axis to be used may otherwise be made on consideration of what reference is most favorable to the optical design, the balance of corrected aberrations, or the expression of the shapes of all the constituent surfaces of the optical system. However, it is general that the path of a ray which arrives at the center of area of the image plane and passes through any one of the center of the stop, or the entrance pupil, or the exit pupil, or the first surface of the optical system and the center of the last surface, is employed as the reference axis for the optical system. In Fig. 5, the light ray. That is, in the embodiments of the invention, determination of the reference axis is made in the steps of selecting a ray which crosses the first surface, or the stop plane, at the center of effective diameter of the light beam and is to arrive at the center of area of the plane on which to form the final image, (or the reference axis ray) and tracing the path to which it is refracted or reflected by or from every one of the refracting and reflecting surfaces. All the surfaces are numbered consecutively as such a ray for the reference axis undergoes successive refractions and reflections.

The reference axis changes its direction, as the selected one of the surfaces changes its number, according to the law of refraction or reflection, finally reaching the center of the image plane; section in the Z axis as zooming goes from 1/2. In every one of the embodiments of the invention, the optical system includes tilted surfaces. The tilting is done as a rule in one and the same plane. So, the axes of the absolute coordinate system are defined as follows. D₂₉ does not move during zooming:

Z-axis: the reference axis passing the original point and going to the second surface R₂; the optical element B₁ and the Y-axis: a line passing the original point and making an angle of 90° with the Z-axis counterclockwise in the tilt plane and (in the paper of Fig. 5); and (above) and the separation between the third optical element B₃ and the image plane, F₂₉X axis: a line passing the original point and perpendicular to each of the Z and Y axes (the normal of the paper of Fig. 5); throughout the entire zooming range.

In the present embodiment, the entering and exiting reference axes of the 6-th optical element B₆ are parallel with each other.

For the other surfaces than the first one, the absolute coordinate system is not suitable for expressing their shapes. To allow the shape of the i-th surface to be recognized at a glance, it is better to make use of a local coordinate system whose original point is taken at the point of intersection of the reference axis with the i-th surface. In the specific embodiments of the invention, therefore, the numerical data of the design parameters for the i-th surface are given by using the local coordinate system of the second embodiment, the example of which is shown in the drawings of Fig. 12. The tilted angle of the i-th surface in the YZ plane is expressed by θ_i (in units of degree), the counterclockwise direction from the Z axis of the absolute coordinate system being taken as positive. In the embodiments of the invention, therefore, the original point of the local coordinate system for each surface lies on the YZ plane in Fig. 5. It should be also noted that any surfaces are not decentered in the XZ and XY planes. Further, the y and z axes of the local coordinate system (x,y,z) for the i-th surface are inclined to the absolute coordinate system (X,Y,Z) by θ_i in the YZ plane. So these axes are defined as follows: By this arrangement, the effective diameter of each of the surfaces of the first optical element B₁ is shortened. This leads to a saving in the diameter in the Y axis. The optical element of compact form is the z axis: the line passing the original point of the local coordinates and making an angle θ_i with the Z direction of the absolute coordinate system counter-clockwise in the YZ plane; and it is intersected with a plurality of other reflecting surfaces: the line passing the original point of the local coordinates and making an angle of 90° with the z direction in the YZ plane; and the height of the light beam in passing through the 6-th optical system. The y axis: the line passing the original point of the local coordinates and perpendicular to the YZ plane.

D_i is in the scalar quantity, representing the separation between the original points of the local coordinates for the i -th and $(i+1)$ st surfaces, and N_{di} and v_{di} are respectively the refractive index and Abbe number of the medium between their i -th and $(i+1)$ st surfaces. Only significance of the optical system must take account any loss of positioning accuracy with another feature of the embodiments of the invention is that the optical system varies the focal length (image magnification) as a plurality of optical elements move. To illustrate the embodiments of the invention by citing numerical data, the optical system is shown in sectional views in three operative positions, namely, the wide-angle end (W), the telephoto end (T) and a middle position (M) therebetween. The numerical data of the variable separations are given in tables. Only the reflecting surfaces arranged in the second relation, the planned amount of one entering aberration. It is to be noted that the optical element of Fig. 5 moves in the YZ plane. By this, what takes different values with different operative positions is the original point (Y_i, Z_i) of the local coordinates for expressing each surface. In the numerical examples of the embodiments, for a case where the optical elements movable for varying the image magnification go along the Z axis, the values Z_i of the coordinates are expressed by $Z_i(W)$, $Z_i(M)$ and $Z_i(T)$ as the optical system is stationed in the wide-angle end, the middle position and the telephoto end, respectively. For another case where the zooming movement occurs in the Y axis, the values Y_i of the coordinates are expressed by $Y_i(W)$, $Y_i(M)$ and $Y_i(T)$ as the optical system is stationed in the wide-angle end, the middle position and the telephoto end, respectively. Incidentally, the values of the coordinate of every surface are expressed in relation of the values for the wide-angle end. The expression of the values for the middle position and the telephoto end is given by the differences from those of the wide-angle end. Specifically, denoting the moved amounts from the wide-angle end (W) to the middle position (M) and the telephoto end (T) by "a" and "b", respectively, the following equations are obtained:

Fig. 10 shows sectional views in the XZ plane of a embodiment of the zoom optical system according to the embodiment. This embodiment includes the following equation: $Z_i(M) = Z_i(W) + a$ in which a is the amount of zoom lens whose range of fit, but b . The numerical data for this form are shown below.

$$Z_i(T) = Z_i(W) + b$$

The sign of the "a" or "b" is positive when the surface moves in the plus direction, or negative when it moves in the minus direction. The same applies to the case of the movement in the Y axis. Such movement causes variation of the separation D_i between the i -th and $(i+1)$ st surfaces. The values of all the variable separations for each of the zooming positions are given together in another tabulation. See table 1.

The surfaces in the embodiments of the invention are either of sphere or of asphere of revolution asymmetry. Of these, the sphere can be described by the radius of curvature R_i . The sign of the radius of curvature R_i is taken as plus when the center of curvature falls in the plus direction of the z axis of the local coordinates, or as minus when it falls in the minus direction of the z axis.

Here, the shape of the spherical surface is expressed by the following equation:

$$\text{Surface Size in mm} = \frac{(x^2 + y^2)/R_i}{1 + \sqrt{1 - (x^2 + y^2)/R_i^2}}$$

The optical system of the invention includes at least one aspheric surface of revolution asymmetry and its shape is expressed by the following equation:

$$z = A/B + C_{02}y^2 + C_{20}x^2 + C_{03}y^3 + C_{21}x^2y + C_{04}y^4 + C_{22}x^2y^2 + C_{40}x^4$$

where

$$A = (a + b)(y^2 \cdot \cos^2 t + x^2)$$

$$B = 2a \cdot b \cdot \cos t [1 + \{(b-a) \cdot y \cdot \sin t / (2a \cdot b)\}] + [1 + \{(b-a) \cdot y \cdot \sin t / (a \cdot b)\} - \{y^2 / (a \cdot b)\}]$$

$$- \{ 4a \cdot b \cdot \cos^2 t + (a+b)^2 \cdot \sin^2 t \} x^2 / [4a^2 b^2 \cdot \cos^2 t]]^{1/2}.$$

5

As far as the variable "x" is concerned; the above-described equation for the curved surface contains only the terms of even numbered powers. Therefore, the surface defined by such an equation becomes a symmetric form with respect to the YZ plane. If it satisfies the following additional condition:

10

$$C_{03} = C_{21} = t = 0,$$

the surface is symmetric with respect to the xz plane. If it satisfies the following furthermore conditions:

$$C_{02} = C_{20},$$

$$C_{04} = C_{40} = C_{22}/2,$$

the surface is of revolution symmetry. In the case of not satisfying the conditions described above, the shape is of revolution asymmetry.

In all the embodiments of the invention except the embodiment 4, the first surface is a stop as shown in Fig. 5. The term "horizontal semifield u_y " means a half of the maximum angular field the system covers at the first surface R1 in the YZ plane of Fig. 5. The term "vertical semifield u_x " means a half of the maximum angular field the system covers at the first surface R1 in the XZ plane. Also, the diameter of the stop is shown as the aperture diameter. This regulates the brightness of the optical system. It is to be noted that, except for the embodiment 4, the entrance pupil takes its place in the first surface. So, the aperture diameter described above is equal to the diameter of the entrance pupil.

Also; the effective area of the image plane is shown as the image size. The image area is of the rectangular shape with the horizontal sides in the y direction of the local coordinates, and the vertical sides in the x direction.

Also; in the numerical examples of the embodiments, the size of the optical system is shown as determined by the effective diameter of the light beam available at the wide-angle end.

The numerical data of design parameters give lateral aberrations which are graphically represented in the operative position of each optical system. For the wide-angle end (W), the middle position (M) and the telephoto end (T), a ray of light is incident on the stop R1 at horizontal and vertical angles of (u_y, u_x) , $(0, u_x)$, $(-u_y, u_x)$, $(u_y, 0)$, $(0, 0)$ or $(-u_y, 0)$ with the production of the lateral aberrations. In the graphs of the lateral aberrations, the abscissa represents the height of incidence on the pupil and the ordinate represents the produced amount of aberration. In any of the embodiments, every surface is basically formed to symmetric shapes in respect to the yz plane. Even in the graphs of the lateral aberrations, therefore, the plus and minus directions of the vertical angular field become the same. So, the graphs of the lateral aberrations of the mirrus direction are omitted for the purpose of simplifying the drawings.

Next, each of the embodiments is described in detail below.

401 ((Embodiment 1))

Design 0790513A2-02
Date 08.10.1979-02

Fig. 1 shows sectional views in the YZ plane of an embodiment 1 of the zoom optical system according to the invention. The present embodiment is applied to the optical system for use in picking up an image to obtain a 3-unit zoom lens. Its design parameters have the numerical values given in tables below.

451 (1) $a = 1.0$ $b = 1.0$
 $C_{01} = 3.6320e-02$
 $C_{02} = 1.3830e-06$
 $C_{03} = 1.2130e-05$

501 (1) $a = 1.0$ $b = 1.0$
 $C_{01} = 1.2130e-02$
 $C_{02} = 1.3830e-06$
 $C_{03} = 1.2130e-05$

551 (1) $a = 1.0$ $b = 1.0$
 $C_{01} = 1.6634e-02$
 $C_{02} = 1.1036e-07$
 $C_{03} = 1.12034e-05$

	W	M	T
Horizontal Semifield	26.3	18.2	9.3
Vertical Semifield	20.3	13.9	7.0
Aperture Diameter	2.4	2.4	2.4

where $C_{01} = 3.5736e-04$ $C_{02} = -3.2385e-04$

W: the wide-angle end;

M: the middle position; and

T: telephoto end

$C_{01} = 0.72725e-04$

$C_{02} = 3.4758me-06$ $C_{03} = -5.09639e-05$

part number, date of issue and the **Image Size in mm (HxV) = 4.8 x 3.6** and take a photo image size of 16.8 x 12.4 mm and the optical system has been designed to fit the image size.

Optics Size at W: (XxYxZ) = 12.4 x 32.9 x 62.0 mm which is equal to the next to find the surface size of the second surface. The second surface has the same height as the first surface.

where H:horizontal; and V:vertical. When the optical system is built, it is necessary to make sure that the refractive surfaces aligned and kept close to the fifth surface R₅, as of the second to last, worked being the two constructed on a common substrate of glass, plastic or any material to form an optical element which is a **planar lens** with $Z_1(W) = 0$ and $\theta_1 = D_1 - N_{D1} \cdot v_{D1}$ Sur.

The total thickness of the lens is 12.4 mm and the distance between the two refractive surfaces is 16.15 mm. The **stop** is taken as the distance between the two refractive surfaces. The distance between the two refractive surfaces is 16.15 mm.

First Optical Element B1:

The following table shows the data which is used to calculate the optical system. The data is as follows:
 1. $Z_1 = 0.00$ and $\theta_1 = 0.00$ for 9.00×10^3 and 1.64769×10^3 and 33.80 mmR.
 2. $Z_2 = 0.00$ and $\theta_2 = 6.15 \times 10^3$ and 0.00 for 9.00×10^3 and 1.64769×10^3 and 33.80 mmR.
 3. $Z_3 = 0.00$ and $\theta_3 = 15.15 \times 10^3$ and 11.66×10^3 and 1.64769×10^3 and 33.80 mmL.

A light ray from the origin passes through the optical element B1, starting from center of mass of point 1 to point 4, then 6.78×10^3 and 5.66×10^3 and 2.45×10^3 is 11.203×10^3 and 1.64769×10^3 and 33.80 mmL. But as in the embodiment of the invention, the reference axis has different factors (orientation). The orientation is taken as 1.5×10^3 and 12.49×10^3 and 15.83×10^3 and 10.81×10^3 and 1.64769×10^3 and 33.80 mmL.

After passing through the optical element of the invention, the light ray is specified by a direction and orientation. It is to be noted that the choice of an axis to be used may depend on the individual consideration of what orientation is most convenient for the optical design. It is also an option to be taken, or the expression of the shapes of all the constituent elements of the optical system. However, it is preferable that the axes of the optical system, at the point of entry of the image plane, pass through the center of the image plane, and vice versa, at the point of exit of the image plane, and vice versa, at the point of entry of the optical system and the center of the last surface, to be employed as the reference axis for the optical system.

That is, in the embodiments of the invention, the choice is made in the steps of selecting a ray which crosses the first surface, or the stop plane, in the direction of effective diameter, of the light beam and is to pass at the point of entry of the image plane straight to the first surface, or the reference axis ray, and back to the path by which it is refracted or reflected by or from every one of the refracting and reflecting surfaces. All the surfaces are symmetrical concentrically so such a ray for the reference axis supports the other refractions and reflections.

The reference axis propagates directly, or the selected one of the surfaces where its number according to the law of refraction, or reflection, finally reaching the center of the image plane.

In every one of the embodiments of the invention, the optical system includes filter surfaces. The filter is done as a rule in one and the same place. So, the axes of the absolute coordinate system are defined as follows:

Z axis: a reference axis passing the origin point and going to the second surface (z).

Y axis: a line passing the original point and making an angle of 90° with the Z axis counter-clockwise in the XY plane (in the paper of Fig. 5); and

X axis: a line passing the original point and perpendicular to each of the Z and Y axes (the normal of the paper of Fig. 5).

For the other surfaces than the first one, the absolute coordinate system is not suitable for expressing their shapes. To solve this, the axes of the local coordinate system is used as a reference axis. The axes of a local coordinate system whose original point is taken at the point of intersection of the reference axis with the (x,y,z) surface, in the embodiment of the invention. Similarly, the optical data of the design parameters for the (x,y,z) surface are given by using the local coordinate system.

Position angle of the (x,y,z) surface in the (X,Y,Z) plane is expressed by α (in units of degree), and counterclockwise direction of the (x,y,z) axes for the absolute coordinate system being taken as positive. In this embodiment of the invention, therefore, the original point of the local coordinate system for each surface lies on the (X,Y,Z) plane in Fig. 5. It should be mentioned that one of the axes of the local coordinate system, the (X,Y) plane, is parallel to the (X,Y) plane of the local coordinate system (x,y,z) as the (x,y,z) are located in the absolute coordinate system (X,Y,Z) in the (X,Y,Z) plane. So, these axes are defined as follows:

X axis: the line passing the original point of the local coordinates, and making an angle of β with the Z axis, in the absolute coordinate system counter-clockwise in the (X,Y) plane;

Y axis: the line passing the original point of the local coordinates and making an angle of γ with the x axis, clockwise, in the (X,Y) plane;

Z axis: the line passing the original point of the local coordinates and perpendicular to the (X,Y) plane.

designed during 1920 through 1924 under a World War II contract. The design was completed in 1924 and the aircraft first flew in 1925. A very good example of the early aircraft designed in the United States is an airplane built on a contract with the U.S. Army.

The element Bf , from calculations calculated 3-complex cation, has the following composition: Li₂Al₂B₁₂O₁₂. The atom No. 5 has a coordination number 7, i.e., -21.71 ± 0.12 ; Bf₃₈ has 22 atoms of Bf. The total atomic charge is 64.769, and the total charge of Bf₃₈ is 33.80. Let us consider the second basis unit. The lithio-calcium element Bf₃₈ constitutes a third base unit. In these three units, and using the results of part 8, we find -21.71 ± 0.12 ; Bf₃₈ has 44.01, their 0.00. Var = 1.00. In this case, the bond length R

10. The function of lens B2 is to converge the light beam by reflecting it. A light beam can be focused or diverged by a lens. (Refer to the notes on lenses) **R** stands for **refracting surface**; **L** for **reflecting surface**. In the diagram, the lens B2 has four surfaces. The first surface is the refracting surface R1, which converges the light beam. The second surface is the reflecting surface L1, which reflects the light beam. The third surface is the refracting surface R2, which diverges the light beam. The fourth surface is the reflecting surface L2, which reflects the light beam.

Second Optical Element B2:

Finally the light beam exiting from the R16 optical element is focused at the twenty-fifth surface of plane R26 on which the diffraction is observed.

Third, the generation of $17.71 \text{ m} \times 17.99 \text{ m}$ at **0.00** m **0.671**, the **1.71736** and **29.51** to the Repetition element B₃, the second optical element B₂ and the third optical element B₃, and is stationary during scanning. The fourth optical element **18.64** moves **-21.71** $\text{m} \times 18.66 \text{ m}$ at **0.00** m . Varying just from the white-angle end to iR-Interphase end, the fifth optical element B₅ simultaneously moves to the plus direction in the Z-axis. The angle plate or the twenty fifth surface. **Third Optical Element B₃:**

During zooming from the wide-angle end to the telephoto end, the separation between the fifth optical element B5 and the fourth optical element B4 decreases by 2.04 mm to 1.58913 mm , and the fifth optical element B5 widens until the separation between the fifth optical element B5 and the image plane P2G widens, into the length of the 21.71 mm . At the same time, the image plane P2G becomes longer as zooming goes from the wide-angle end to the telephoto end.

40 elements 22, 24 and 25 are parallel with each other and oriented to opposite directions.

The lateral derivatives of the zeta function of the outer and innermost segments are shown in the graphs of Figs. 15, 16 and 17.

For the collating purposes, the first control element R² is moved by the Z axis to still 1 different object distances. An average value of the parameters is taken and it is found that the area R² is disposed adjacent to the 45th surface to the left at which a light beam first enters a given optical system and there an image of an object is formed in the region of -21.71 to -38.48 with a 0.00 optical 2.85 merit 1.755201127151 aberration; the 25th element of each of the surfaces of these optical elements is shortened. This leads to narrowing the diaphragm in the Z axis to 26 optics 21.71 or -41 to 32 mm 0.00 depth 0.10 1 R

Another advantage arises from the fact that the second, fourth and fifth optical elements B2, B4 and B5 each are provided with **2.7x** **lens** **-21** **to** **71** **center** **41**, **.42** **edges** **0.00** **are** **0.59** **proper** **1.465446** **power** **33.62** **angle** **R** **in** **decentered** **relation**. This allows the light beam inside the main optical system to be folded for a desired shape without causing the light beam **28** **to** **21** **to** **71** **center** **41** **92** **total** **0.00** **Var** **fraction** **1** **is** **thus** **shortened**. **R**

Yet another advantage arising from the fact that the second, fourth and fifth optical elements B2, B4 and B5 each have its reflecting surfaces formed on a rigid transparent body is that the reflecting surfaces can be positioned in a uniform tolerance (assembly tolerance) which greatly affects the optical performance. The optical system thus fully suffuses any loss of positioning accuracy with no loss.

Furthermore, the zoom optical system has its first lens element B1 constructed with coaxial refracting surfaces as is formed a coaxial lens element. Therefore, the focusing mechanism becomes simpler in structure.

Another feature of the invention is that the entering reference axis of the first optical element 231 which does not

	$C_{03}=4.89807e-03$	$C_{21}=2.67721e-03$	
	$C_{04}=1.88551e-04$	$C_{22}=-2.04184e-04$	$C_{40}=1.07399e-04$
5	$R_5: a=-2.03427e+01$	$b=-2.34954e+01$	$t=3.70433e+01$
	$C_{03}=5.02647e-04$	$C_{21}=1.88611e-04$	
	$C_{04}=2.09495e-05$	$C_{22}=2.42572e-06$	$C_{40}=-1.92403e-06$
10			Stop
			Optical Element B1
	$R_6: a=-1.22106e+02$	$b=-1.22097e+02$	$t=7.58653e+01$
	$C_{03}=4.66466e-04$	$C_{21}=4.88673e-05$	
	$C_{04}=-4.14548e-05$	$C_{22}=-1.09844e-04$	$C_{40}=6.05085e-05$
15	$R_7: a=-1.45959e+01$	$B=1.84911e+02$	$t=2.98825e+01$
	$C_{03}=2.73516e-04$	$C_{21}=5.85397e-05$	
	$C_{04}=-2.28623e-06$	$C_{22}=-6.14890e-06$	$C_{40}=-8.24738e-06$

In Fig. 1, the first surface R1 is a stop at which the entrance pupil lies. A first optical element B1 is constructed with a second surface R2 (refracting entrance surface), a third surface R3 to a seventh surface R7 of internal reflection in curved form, and an eighth surface R8 (refracting exit surface) arranged on one block. A second optical element B2 is constructed with a number of lenses with ten refracting surfaces, or the ninth surface R9 through the eighteenth surface R18 arranged on a common optical axis. A third optical element B3 is constructed with a number of lenses with ten refracting surfaces, or the nineteenth surface R19 through the twenty eighth surface R28 arranged on a common optical axis. A twenty ninth surface R29 is the image plane in which the image receiving surface of an image pickup device such as a CCD lies.

The present embodiment is to form a so-called 3-unit zoom lens. The stop R1 and the first optical element B1 constitute a first lens unit. The second optical element B2 constitutes a second lens unit. The third optical element B3 constitutes a third lens unit. Of these, the second and third lens units vary their relative positions to perform the function of varying the focal length.

Next, the image forming function is described on the assumption that an object is at infinity. A light beam passing through the stop R1, enters the first optical element B1 and is refracted by the second surface R2. Inside the first optical element B1, it is reflected from the successive surfaces R3 through R7. When exiting from the first optical element B1, the light beam is refracted by the eighth surface R8. During this time, the light beam is once focused to form an intermediate image in the neighborhood of the fourth surface R4. Further, a second image is formed in the space between the first and second optical elements B1 and B2.

The light beam then enters the second optical element B2, within which it is refracted by all the surfaces R9 through R18 and then exits therefrom. At this time, the principal ray of the light beam is focused in the neighborhood of the eighteenth surface R18 to form a pupil.

Next, the light beam exiting from the second optical element B2 enters the third optical element B3, within which it is refracted by all the surfaces R19 through R28, and exits therefrom, reaching the twenty ninth surface or plane R29 on which the final image is formed.

Next, the operation of varying the image magnification is described. During zooming, the first optical element B1 remains stationary. The second optical element B2 first moves to the plus direction in the Z axis as zooming goes from the wide-angle end toward the telephoto end, and then to the minus direction in the Z axis. The third optical element B3 moves to the plus direction in the Z axis, as zooming goes from the wide-angle end to the telephoto end. The image plane or the twenty ninth surface R29 does not move during zooming.

By zooming from the wide-angle end to the telephoto end, the separation between the first optical element B1 and the second optical element B2 first narrows and then widens, the separation between the second optical element B2 and the third optical element B3 narrows, and the separation between the third optical element B3 and the image plane R29 widens. Also, the length of the optical path of the entire system beginning with the first surface R1 and terminating at the image plane R29 is kept constant during zooming from the wide-angle end to the telephoto end.

In the present embodiment, the entering and exiting reference axes of the first optical element B1 are parallel to each other and oriented to opposite directions. The second optical element B2 and the third optical element B3 which perform the function of varying the image magnification have their reference axes in coincidence with the optical axes thereof, which are common with each other. The entering and exiting reference axes of each of the second and third optical elements B2 and B3 are oriented to the same direction.

The lateral aberrations of the zoom optical system of the present embodiment are shown in the graphs of Figs. 2, 3 and 4.

For the focusing purposes, the stop R1 and the first optical element B1 are moved in unison to the Z axis to suit to different object distances.

An advantage of the present embodiment arises from the facts that the stop R1 is disposed on the object side of

the zoom optical system and that two images of an object are formed in the interior of the first optical element B1 and behind the first optical element B1. By this arrangement, the effective diameter of each of the surfaces of the first optical element B1 is shortened. This leads to minimize the dimension in the X axis. The optical element of compact form is thus obtained.

Another advantage arises from the fact that the first optical element B1 is provided with a plurality of inner reflecting surfaces which are given proper refractive powers and arranged in decentered relation. This allows the optical path to be bent to a desired shape without having to mutilate the light beam in passing through the zoom optical system. The total length in the Z direction is thus shortened.

Yet another advantage arising from the fact that the first optical element B1 has its reflecting surfaces formed on a rigid transparent body is that the reflecting surfaces can be positioned in a uniform tolerance (assembling tolerance) which greatly affects the optical performance. The optical system thus little suffers any loss of positioning accuracy with aging.

Further, the zoom optical system is made up by employing two different types of optical elements in good combination, one of which has a plurality of reflecting surfaces formed in unison and the other of which is constructed with the coaxial refracting surfaces (coaxial optical element). As compared with the case where the zoom optical system is constructed only with the reflecting surfaces arranged in decentered relation, the produced amount of decentering aberrations is more suppressed by having the coaxial optical element made to share the refractive power. The use of the optical element which is composed of coaxial refracting spherical surfaces facilitates the easiness of correcting all aberrations.

Furthermore, such an optical element of coaxial refracting spherical surfaces is easy to manufacture.

(Embodiment 2)

Fig. 6 shows sectional views in the YZ plane of an embodiment 2 of the zoom optical system according to the invention. The present embodiment is applied to the optical system for use in picking up an image and provides a 3-component zoom lens. The numerical data for this embodiment are shown below.

	R	-17.81	7.96	0.12	R
	W	M	T	W	R
Horizontal Semifield	20.3	13.9	7.0		
Vertical Semifield	26.3	18.2	9.3		
Aperture Diameter	2.4	2.4	2.4		

Image Size in mm: (H x V) = 3.6 x 4.8

Optics Size at W: (XxYxZ) = 8.8 x 77.9 x 15.6

The following sections will describe the general properties of the elements and their applications.

id	Zi(Yi)	Zi(Wi)	Di	Dri	Ndi	vdi	Start	End
1	0.00	0.00	0.00	2.25	1	0.00	Stop	100%

First Optical Element B1: at different object distances.

First Optical Element B1 at different object distances.

Based on the object side of the interface, the B2 is the most effective solution.

On June 26, 1994, the **6.74** usd **3.42** bbo **12.37** bbl **8.75** bbl **1.51633** **64.15** usd oil futures closed at a record high of \$12.37/bbl, up 15 cents from a previous weekly high.

5. In addition to the above, the following were also present:

8 -22.05 0.68 -46.66 5.80 1.51633 64.15 L R

Second Optical Element B2: The second optical element of the zoom objective is formed by employing a number of optical elements.

Second Optical Element B2:

of two years in great contrast to the other 60% which had been in office less than one year.

the refractive power of the lens
is **-42.68**, the focal length
13 cm.

It must be noted that since in the present embodiment the third patient element 186 is a negative lens, the direction of the light rays from the second patient element 184 is reversed by the third patient element 186.

The resulting reference axis from the sixth optical element is the same as the reference axis of the entire telescope assembly.

MS. B. 1.6. 19, fol. 45v: The object is oriented vertically, and the text is written in the perpendicular direction (vertical).

Third Optical Element B3: The third optical element is a biconvex lens with a focal length of 100 mm. It is positioned at a distance of 100 mm from the second lens. The lens has a refractive index of 1.52 and a diameter of 50 mm. The lens is oriented such that its principal axis is parallel to the X-axis and its center of curvature is located at the same height as the center of curvature of the second lens.

As the above-described optical system comprising a plurality of optical elements, including an optical train having two reflecting surfaces and a plurality of reflecting surfaces.

acted, formed in a transporer 22 **61.80** **0.68** **90.00** **0.58** **1.58918** **61.18** **Re** transparent body from
 One of the two reflecting surfaces and, after being separated, indicated from the reflecting surfaces, consists of two reflecting surfaces, and is
 to the other of the two reflecting surfaces, and is
 23 **63.38** **0.68** **90.00** **0.10** **1** **plasticity**
 critical element composed of plasticity
 24 **62.48** **0.68** **90.00** **2.76** **1.60729** **59.37** **of** **plasticity**
 plasticity is a material having

24	63.48	0.68	-90.00	2.76	1.69/29	59.81
25	-66.23	0.68	-90.00	3.20	1.75520	27.51
26	-66.23	0.68	-90.00	3.20	1.75520	27.51

28 -70.03 0.68 -90.00 Var. 1 R. I.P.
 quality of optical elements, and 29 -74.72 0.68 -90.00 0.00 1 R. I.P.
 quality of optical elements

Besides these, according to the invention, the zoom-optical element 124 and/or the lens optical element 86 in the embodiment 1 may be otherwise constructed with a plurality of surface mirrors, successively from one another, and move up in unison, such that the entering light beam repeats reflection from the successive surface mirrors before it exits. In this case, there is produced an advantage of reducing the weight of the zoom-optical system.

Also, in the invention, for the optical element which contributes to a variation of the focal length, the direction of zooming movement is not necessarily parallel to the direction of the entering reference axis to the zoom optical system. Depending on the situation of the design of the image pickup apparatus, the direction of zooming movement of the optical element may be changed to an angle of, for example, 30°-45° or 60° with respect to the entering reference axis to the zoom optical system by inclining the entering reference axis of the last optical element.

Other features of the cognitive system will be described below.

	Surface	Radius	Thickness	Material	Abbe Number	Numerical Aperture	Transmittance
5	R1	-1.27855e+01	0.00000e+00	air	1.00000e+00	1.00000e+00	1.00000e+00
	R2	1.26579e-04	0.00000e+00	air	1.00000e+00	1.00000e+00	1.00000e+00
	R3	4.24795e-05	0.00000e+00	air	1.00000e+00	1.00000e+00	1.00000e+00
10	R4	1.26913e-03	0.00000e+00	air	1.00000e+00	1.00000e+00	1.00000e+00
	R5	1.26579e-04	0.00000e+00	air	1.00000e+00	1.00000e+00	1.00000e+00
	R6	1.26913e-03	0.00000e+00	air	1.00000e+00	1.00000e+00	1.00000e+00
15	R7	1.26579e-04	0.00000e+00	air	1.00000e+00	1.00000e+00	1.00000e+00
	R8	1.26913e-03	0.00000e+00	air	1.00000e+00	1.00000e+00	1.00000e+00
20	R9	1.26579e-04	0.00000e+00	air	1.00000e+00	1.00000e+00	1.00000e+00
	R10	1.26913e-03	0.00000e+00	air	1.00000e+00	1.00000e+00	1.00000e+00
25	R11	1.26579e-04	0.00000e+00	air	1.00000e+00	1.00000e+00	1.00000e+00
	R12	1.26913e-03	0.00000e+00	air	1.00000e+00	1.00000e+00	1.00000e+00
30	R13	1.26579e-04	0.00000e+00	air	1.00000e+00	1.00000e+00	1.00000e+00
	R14	1.26913e-03	0.00000e+00	air	1.00000e+00	1.00000e+00	1.00000e+00
35	R15	1.26579e-04	0.00000e+00	air	1.00000e+00	1.00000e+00	1.00000e+00
	R16	1.26913e-03	0.00000e+00	air	1.00000e+00	1.00000e+00	1.00000e+00
40	R17	1.26579e-04	0.00000e+00	air	1.00000e+00	1.00000e+00	1.00000e+00
	R18	1.26913e-03	0.00000e+00	air	1.00000e+00	1.00000e+00	1.00000e+00
45	R19	1.26579e-04	0.00000e+00	air	1.00000e+00	1.00000e+00	1.00000e+00
	R20	1.26913e-03	0.00000e+00	air	1.00000e+00	1.00000e+00	1.00000e+00
50	R21	1.26579e-04	0.00000e+00	air	1.00000e+00	1.00000e+00	1.00000e+00
	R22	1.26913e-03	0.00000e+00	air	1.00000e+00	1.00000e+00	1.00000e+00
55	R23	1.26579e-04	0.00000e+00	air	1.00000e+00	1.00000e+00	1.00000e+00
	R24	1.26913e-03	0.00000e+00	air	1.00000e+00	1.00000e+00	1.00000e+00
60	R25	1.26579e-04	0.00000e+00	air	1.00000e+00	1.00000e+00	1.00000e+00
	R26	1.26913e-03	0.00000e+00	air	1.00000e+00	1.00000e+00	1.00000e+00
65	R27	1.26579e-04	0.00000e+00	air	1.00000e+00	1.00000e+00	1.00000e+00
	R28	1.26913e-03	0.00000e+00	air	1.00000e+00	1.00000e+00	1.00000e+00
70	R29	1.26579e-04	0.00000e+00	air	1.00000e+00	1.00000e+00	1.00000e+00

	W	M	T
D 9	11.07	4.69	6.29
D19	12.88	8.74	1.44
D28	4.69	14.71	20.42

- 10 R 1 + up to R9: $Y(M) = Y(W) + \alpha_0$
 $Y(T) = Y(W)$
- 15 R10 + up to R19: $\alpha_4 \cdot Y(M) = Y(W) - 6.39$
 $Y(T) = Y(W) - 4.78$
- 20 R20 + up to R28: $\alpha_4 \cdot Y(M) = Y(W) - 10.02$
 $Y(T) = Y(W) - 15.73$
- 25 R29: $\alpha_4 \cdot Y(M) = Y(W)$ (the image of the object is upright). After exiting element B1, a diverging ray (the second surface R1 is a divergent surface). A diverging ray from the first surface R10 (exit pupil) is imaged on the rightmost lens block. A second optical element B2 is positioned between the two diverging surfaces. On the right surface R9 it meets the rightmost lens block. An image formed on the central optical axis. A third optical element B3 is positioned with a number of lenses with ten R 2 Surface: $R_2 = \infty$ (the distance from the lens block to the image plane), that along the NPF an image is formed in the plane R 9 Surface: $R_9 = -14.692$ cm (it is the image plane in which the image receives a picture of an image pickup device R10 Surface: $R_{10} = 15.785$
- 30 R11 Surface: $R_{11} = -9.916$ cm is located to obtain a real zooming. The step R1 is the first optical element B1 from R12 Surface: $R_{12} = 806.578$ cm (the second lens of the first optical element B1) to its second lens unit. Then the first optical element B3 from R13 Surface: $R_{13} = -19.136$ cm (the second and third lens units are placed very close to each other to shorten the length of R14 Surface: $R_{14} = 24.764$
- 35 R15 Surface: $R_{15} = 26.101$ no function is described on the assumption that an object is at infinity. A light beam passing R16 Surface: $R_{16} = 7.532$ cm (the first optical element B1) and is stretched by the second surface R2, incident the first optical R17 Surface: $R_{17} = 123.778$ cm (the specific surface R2 through R7). When exiting from the first optical element B1 R18 Surface: $R_{18} = -52.093$ cm (the eighth surface R8). During this time, the image beam is once focused to form an intermediate R19 Surface: $R_{19} = 5.947$ cm (the back of the ninth surface R9). Further, a second image is formed in the space between R20 Surface: $R_{20} = 113.146$ elements B1 and B2.
- 40 R21 Surface: $R_{21} = 19.210$ cm (the second optical element B2, within which it is refracted by all the surfaces R9 through R22 Surface: $R_{22} = 16.059$ cm. At this time, the principal ray of the light beam is focused in the neighborhood of the right R23 Surface: $R_{23} = -106.475$ cm.
- 45 R24 Surface: $R_{24} = 16.867$ exiting from the second optical element B2 enters the third optical element B3, within which it is R25 Surface: $R_{25} = 47.880$ cm (the first lens of the third optical element B3 through R26). And exits therefrom reaching the twenty ninth surface or ninth R29 R26 Surface: $R_{26} = -28.891$ cm formed.
- 50 R27 Surface: $R_{27} = 6.381$ of varying the image magnification is described. During zooming, the first optical element B1 R28 Surface: $R_{28} = 5.013$ second optical element B2 moves to the plus direction in the Z axis as zooming goes from the wide-angle end toward the telephoto end, and then to the minus direction in the Z axis. The third optical element B3 Shape of Aspheric Surface: in the Z axis, as zooming goes from the wide-angle end to the telephoto end. The image distance of each surface R29 does not change during zooming.
- 55 R 3: $a = -3.59218e+01$ with $b = 9.56407e+00$; $t = 2.62788e+01$ situated between the first optical element B1 and the second optical element B2; $C_{03} = -3.28591e-04$ and $C_{21} = 1.09040e-04$ the separation between the second optical element B2 and $C_{04} = 3.02002e-05$ and $C_{22} = 7.83327e-05$ the third optical element B3 and the image plane $C_{40} = 7.31472e-05$ (the length of the optical path of the whole system beginning with the first surface R1 and terminating R 4: $a = 4.46438e+00$ with $b = 7.31244e+00$; $t = 1.05955e+01$ situated to the telephoto end
- 60 $C_{03} = -8.43381e-04$ and $C_{21} = 1.15148e-04$ exiting reference axes of the first optical element B1 are parallel to each other; $C_{04} = 4.92526e-04$ and $C_{22} = -1.32799e-03$ and $C_{40} = -3.19191e-04$ and the third optical element B3 which performs the function of varying the image magnification or have their reference axes in coincidence with the optical axis R 5: $a = -1.27855e+01$ with $b = 2.36243e+01$ and $t = 1.82299e+01$ reference axes of each of the second and third optical elements $C_{03} = 4.49533e-05$ and $C_{21} = 4.24795e-05$ and circulation $C_{04} = -2.72263e-05$ and $C_{22} = -1.26579e-04$ elements are shown in the optical of Figs. 2, 3 and 4.
- 65 R 6: $a = -9.17197e+00$ with $b = -4.60643e+01$ and $t = 1.12881e+01$ R1 are moved in a step in the Z axis to cut to $C_{03} = 8.58718e-05$ and $C_{21} = -8.69345e-04$ $C_{04} = 3.09227e-04$ and $C_{22} = -9.83897e-04$ and $C_{40} = -1.26913e-03$ a step in the Z axis deposited on the object side of

The R1: $a = -1.38671e+01$, $b = 2.68360e+01$ and $c = 1.28619e+01$ provides for the image plane.

The $C_{03} = 1.27138e-05$, $C_{04} = 3.07799e-04$, C_{15} (portion preceding the stop) and $C_{16} = 2.23030e-05$ to the stop, $C_{05} = 8.55028e-06$, $C_{06} = 5.67380e-05$ to $C_{40} = 8.71918e-05$, the portion of the reference plane coincident with the stop, are relevant to the calculation of the aberration coefficients. All other parameters have been defined.

5 R18: $a = -7.86361e+01$, $b = 5.55994e+01$ and $c = 7.05431e+01$ is the image plane. The lenslet L1 is not accounted for since $C_{03} = -1.26030e-04$, $C_{04} = 2.06017e-05$ and $C_{21} = -1.97414e-03$ is of the effect of a light beam at the center of the optical system.

10 $C_{04} = 2.06017e-05$ is of the $C_{22} = -2.60272e-05$ and $C_{40} = -3.06310e-04$ is perspective view of the lenslet L1, a biconvex spacer element to the first optical element L1 is followed with two refracting surfaces 41 and 42 and two reflecting surfaces.

15 In Fig. 6, the first surface R1 is a stop that is the entrance pupil. A first optical element B1 is constructed with a second surface R2 (refracting entrance surface), six curved inner reflecting surfaces R3 through R8 and a ninth surface R9 (refracting exit surface) arranged on one block. A second optical element B2 is constructed with a number of lenses with ten coaxial refracting surfaces R10 through R19. A third optical element B3 is constructed with a number of lenses with nine coaxial refracting surfaces R20 through R28. A twenty ninth surface R29 is the image plane coincident with the

15 image receiving surface of an image pickup device such as a CCD. From time to time, according to the drawings, the present embodiment is to provide a so-called 3-unit zoom lens. The stop R1 and the first optical element B1 constitute a first lens unit. The second optical element B2 constitutes a second lens unit. The third optical element B3 constitutes a third lens unit. Of these, the second and third lens units constitute a zoom section and move in differential

20 relation to vary the focal length, thereby adapting the zooming to the applications. Also, there is no need to move the lens units.

25 Next, the function of forming an image with an object at infinity is described. A light beam that has passed through the stop R1 enters the first optical element B1. In the interior of the first optical element B1, the light beam is refracted by the second surface R2, then reflected from the third surface R3, the fourth surface R4, the fifth surface R5, the sixth surface R6, the seventh surface R7 and the eighth surface R8 and then refracted by the ninth surface R9, exiting from the first optical element B1. During this time, the light beam is once focused to form an intermediate image in the neighborhood of the fourth surface R4. Further, a second image is formed in the space between the first optical element B1 and the second optical element B2, reflected by the surfaces R10 through R19.

30 The light beam then enters the second optical element B2. In the interior of the second optical element B2, the light beam is refracted by the surfaces R10 through R19 and then exits therefrom. At this time, the principal ray of the light beam is focused behind the nineteenth surface R19 to form a pupil. Optical elements are selected for the second lens unit.

35 Next, the light beam that has exited from the second optical element B2 enters the third optical element B3. In the interior of the third optical element B3, the light beam is refracted by the surfaces R20 through R28, and exits therefrom, reaching the twenty ninth surface or plane R29 on which a final image is formed. With its F1, G1, G2 and G3 magnification.

40 Next, the operation of varying the image magnification is described. The first optical element B1 remains stationary during zooming. The second optical element B2 first moves to the plus direction in the Y axis as zooming goes from the wide-angle end toward the telephoto end, and then to the minus direction in the Y axis. The third optical element B3 simultaneously moves to the plus direction in the Y axis. The image plane or the twenty ninth surface R29 does not move during zooming. The present embodiment is the same as that of the embodiment 6.

45 By zooming from the wide-angle end to the telephoto end, the separation between the first optical element B1 and the second optical element B2 first narrows and then widens, the separation between the second optical element B2 and the third optical element B3 narrows, and the separation between the third optical element B3 and the image plane R29 widens. Also, the length of the optical path of the entire system from the first surface R1 to the image plane R29 is kept constant throughout the entire zooming range.

50 In the present embodiment, the entering and exiting reference axes of the first optical element B1 make an angle of .90° with each other. The second optical element B2 and the third optical element B3 which perform the function of varying the image magnification have their reference axes in coincidence with the optical axes thereof, which are common with each other. The entering and exiting reference axes of each of the second and third optical elements B2 and B3 are oriented to the same direction, with the exception of the lateral aberrations of the zoom optical system of the present embodiment are shown in the graphs of Figs. 7, 8 and 9, units move in differential relation during zooming. That is, the first optical element B1 is used as a first lens unit. For the focusing purposes, the stop R1 and the first optical element B1 are moved in unison to the Y axis to suit to different object distances. This produces an advantage of reducing the range of variation of the entering spherical aberration.

55 An advantage of the present embodiment arises from the facts that the stop R1 is disposed on the object side of the zoom optical system and that two images of an object are formed in the interior of the first optical element B1 and behind the first optical element B1. By this arrangement, the effective diameter of each of the surfaces of the first optical element B1 is shortened. This leads to minimize the dimension in the X axis. The optical element of compact form is thus obtained, efficient for构成 a 3-unit zoom optical system.

60 Another advantage arises from the fact that the first optical element B1 is provided with a plurality of inner reflecting surfaces which are given proper refractive powers and an angled in decentered relation. This allows the optical path to be bent to a desired shape without having to mutilate the light beam in passing through the zoom optical system. The total length in the Z direction is thus shortened, expressed by the differences from those of the wide-angle end

Yet another advantage arising from the fact that the first optical element B1 has its reflecting surfaces formed on a rigid transparent body is that the reflecting surfaces can be positioned in a uniform tolerance (assembling tolerance) which greatly affects the optical performance. The optical system thus little suffers any loss of positioning accuracy with aging.

- 5 Further, the zoom optical system is made up by employing two different types of optical elements in good combination, one of which has a plurality of reflecting surfaces formed in unison and the other of which is constructed with the coaxial refracting surfaces (coaxial optical element). As compared with the case where the zoom optical system is constructed only with the reflecting surfaces arranged in decentered relation, the produced amount of decentering aberrations is more suppressed by having the coaxial optical element made to share the refractive power. The use of the
10 optical element which is composed of coaxial refracting spherical surfaces facilitates the easiness of correcting all aberrations.

Furthermore, such an optical element of coaxial refracting spherical surfaces is easy to manufacture.

(Embodiment 3)

Fig. 10 shows sectional views in the YZ plane of an embodiment 3 of the zoom optical system according to the invention. This embodiment is applied to the optical system for use in picking up an image and provides a 3-component zoom lens whose range is about 3. The numerical data for this lens are shown below.

Second Optical Element B2:

		W	M	T
	Horizontal Semifield	26.3	18.2	9.3
	Vertical Semifield	20.3	13.9	7.0
	Aperture Diameter	2.5	2.5	2.5

Image Size in mm: (H x V) = 4.8 x 3.6

Optics' Size at W: (XxYxZ) = 11.8 x 41.2 x 55.7

Third Optical Element B3:

20	-60.21	0.68	-90.00	1.48	1.53213	61.18	R
21	-48.96	0.68	-90.00	1.49	1.53213	61.18	R
22	-63.89	0.68	-90.00	1.49	1.53213	61.18	R
23	-60.38	0.68	-90.00	1.50	1.53213	61.18	R
24	-63.46	0.68	-90.00	1.76	1.59728	59.97	R
25	-96.93	0.68	-90.00	3.20	1.13793	27.51	S
26	-69.12	0.68	-90.00	1.49	1.53213	61.18	R
27	-80.41	0.68	-90.00	1.59	1.53213	61.18	R
28	-73.00	0.68	-90.00	1.61	1.53213	61.18	R
29	-74.72	0.68	-90.00	1.66	1.53213	61.18	R

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Spectrograph and VPHG designed by J. Strigl. Optical system of spectrograph and VPHG. The individual components are numbered in accordance with Fig. 34. The optical system consists of three lenses and a stop. The lens elements are mounted on a common base plate.

i	Yi	Zi(W)	θ_i	Di	Ndi	vdi	Sur.
1	0.00	0.00	0.00	5.12	1		Stop
First Optical Element B1:							
2	0.00	5.12	0.00	7.50	1.58310	30.20	R
3	0.00	12.62	25.00	11.00	1.58310	30.20	L
4	-8.43	5.55	3.29	10.00	1.58310	30.20	R
5	-15.30	12.82	-15.05	9.50	1.58310	30.20	L
6	-17.49	3.57	13.42	10.00	1.58310	30.20	R
7	-23.94	11.22	2.15	10.00	1.58310	30.20	L
8	-30.94	4.08	22.22	7.99	1.58310	30.20	R
9	-30.94	12.06	0.00	Var.	1		R
Second Optical Element B2:							
10	-30.94	27.17	0.00	1.97	1.56873	63.16	R
11	-30.94	29.15	0.00	0.10	1		R
12	-30.94	29.25	0.00	1.68	1.62041	60.27	R
13	-30.94	30.93	0.00	0.10	1		R
14	-30.94	31.03	0.00	1.99	1.62041	60.27	R
15	-30.94	33.02	0.00	0.10	1		R
16	-30.94	33.12	0.00	2.36	1.62280	57.06	R
17	-30.94	35.48	0.00	0.10	1		R
18	-30.94	35.58	0.00	7.50	1.72151	29.24	R
19	-30.94	36.08	0.00	Var.	1		R
Third Optical Element B3:							
20	-30.94	48.80	0.00	1.48	1.58913	61.18	R
21	-30.94	50.28	0.00	0.10	1		R
22	-30.94	50.38	0.00	1.58	1.58913	61.18	R
23	-30.94	51.96	0.00	0.10	1		R
24	-30.94	52.06	0.00	2.76	1.60729	59.37	R
25	-30.94	54.82	0.00	3.20	1.75520	27.51	R
26	-30.94	58.02	0.00	0.10	1		R
27	-30.94	58.12	0.00	0.50	1.59551	39.28	R
28	-30.94	58.62	0.00	Var.	1		R
29	-30.94	61.58	0.00	0.00	1		I.P.

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D9	15.11	4.81	6.79	
D19	12.71	10.22	3.53	
D28	2.96	15.75	20.46	

5. **Surface R1:** $R_1 = -1346715.00$, $a = 1.00000e+00$, $b = 0.00000e+00$, $c = 0.00000e+00$, $d = 0.00000e+00$, $e = 0.00000e+00$, $f = 0.00000e+00$, $t = 0.00000e+00$. **Surface R1 + up to R9:** $Zi(M) = Zi(W)$ (where $i = 1, 2, \dots, 9$) is provided with a constant refractive index $n_i = 1.5167$ and a constant dispersion coefficient $V_i = 0.0000$. **Surface R10 + up to R19:** $Zi(M) = Zi(W) + 10.30$ (where $i = 10, \dots, 19$). A second optical element E2 is concatenated with a number of surfaces $i = 10, \dots, 19$. $Zi(T) = Zi(W) + 8.32$ (where $i = 10, \dots, 19$). A zooming system is provided with a variable focal length f_z and a variable $Zi(T) = Zi(W)$ (where $i = 10, \dots, 19$) coincident with the focal length f_z . **Surface R20 + up to R28:** $Zi(M) = Zi(W) - 12.79$ (where $i = 20, \dots, 28$).
10. **Surface R29:** $R_2 = -1.00000e+00$, $a = 1.00000e+00$, $b = 0.00000e+00$, $c = 0.00000e+00$, $d = 0.00000e+00$, $e = 0.00000e+00$, $f = 0.00000e+00$, $t = 0.00000e+00$. **Surface R30:** $R_3 = 1.00000e+00$, $a = 1.00000e+00$, $b = 0.00000e+00$, $c = 0.00000e+00$, $d = 0.00000e+00$, $e = 0.00000e+00$, $f = 0.00000e+00$, $t = 0.00000e+00$. **Surface R31:** $R_4 = 1.00000e+00$, $a = 1.00000e+00$, $b = 0.00000e+00$, $c = 0.00000e+00$, $d = 0.00000e+00$, $e = 0.00000e+00$, $f = 0.00000e+00$, $t = 0.00000e+00$.
15. **Shape of Spherical Surface:** $R_{10} = 1.00000e+00$, $R_{11} = 1.00000e+00$, $R_{12} = 1.00000e+00$, $R_{13} = 1.00000e+00$, $R_{14} = 1.00000e+00$, $R_{15} = 1.00000e+00$, $R_{16} = 1.00000e+00$, $R_{17} = 1.00000e+00$, $R_{18} = 1.00000e+00$, $R_{19} = 1.00000e+00$, $R_{20} = 1.00000e+00$, $R_{21} = 1.00000e+00$, $R_{22} = 1.00000e+00$, $R_{23} = 1.00000e+00$, $R_{24} = 1.00000e+00$, $R_{25} = 1.00000e+00$, $R_{26} = 1.00000e+00$, $R_{27} = 1.00000e+00$, $R_{28} = 1.00000e+00$, $R_{29} = 1.00000e+00$, $R_{30} = 1.00000e+00$, $R_{31} = 1.00000e+00$, $R_{32} = 1.00000e+00$, $R_{33} = 1.00000e+00$, $R_{34} = 1.00000e+00$, $R_{35} = 1.00000e+00$, $R_{36} = 1.00000e+00$, $R_{37} = 1.00000e+00$, $R_{38} = 1.00000e+00$, $R_{39} = 1.00000e+00$, $R_{40} = 1.00000e+00$.
20. **Surface R2:** $R_2 = -9.470$ (where $i = 2$), $a = 1.00000e+00$, $b = 0.00000e+00$, $c = 0.00000e+00$, $d = 0.00000e+00$, $e = 0.00000e+00$, $f = 0.00000e+00$, $t = 0.00000e+00$. **Surface R9:** $R_9 = -12.397$ (where $i = 9$), $a = 1.00000e+00$, $b = 0.00000e+00$, $c = 0.00000e+00$, $d = 0.00000e+00$, $e = 0.00000e+00$, $f = 0.00000e+00$, $t = 0.00000e+00$. **Surface R10:** $R_{10} = -18.096$ (where $i = 10$), $a = 1.00000e+00$, $b = 0.00000e+00$, $c = 0.00000e+00$, $d = 0.00000e+00$, $e = 0.00000e+00$, $f = 0.00000e+00$, $t = 0.00000e+00$. **Surface R11:** $R_{11} = -12.488$ (where $i = 11$), $a = 1.00000e+00$, $b = 0.00000e+00$, $c = 0.00000e+00$, $d = 0.00000e+00$, $e = 0.00000e+00$, $f = 0.00000e+00$, $t = 0.00000e+00$. **Surface R12:** $R_{12} = -22.656$ (where $i = 12$).
25. **Surface R13:** $R_{13} = -11.326$ (where $i = 13$), $a = 1.00000e+00$, $b = 0.00000e+00$, $c = 0.00000e+00$, $d = 0.00000e+00$, $e = 0.00000e+00$, $f = 0.00000e+00$, $t = 0.00000e+00$. **Surface R14:** $R_{14} = 39.448$ (where $i = 14$), $a = 1.00000e+00$, $b = 0.00000e+00$, $c = 0.00000e+00$, $d = 0.00000e+00$, $e = 0.00000e+00$, $f = 0.00000e+00$, $t = 0.00000e+00$. **Surface R15:** $R_{15} = -16.896$ (where $i = 15$), $a = 1.00000e+00$, $b = 0.00000e+00$, $c = 0.00000e+00$, $d = 0.00000e+00$, $e = 0.00000e+00$, $f = 0.00000e+00$, $t = 0.00000e+00$. **Surface R16:** $R_{16} = 7.231$ (where $i = 16$), $a = 1.00000e+00$, $b = 0.00000e+00$, $c = 0.00000e+00$, $d = 0.00000e+00$, $e = 0.00000e+00$, $f = 0.00000e+00$, $t = 0.00000e+00$. **Surface R17:** $R_{17} = -53.267$ (where $i = 17$), $a = 1.00000e+00$, $b = 0.00000e+00$, $c = 0.00000e+00$, $d = 0.00000e+00$, $e = 0.00000e+00$, $f = 0.00000e+00$, $t = 0.00000e+00$. **Surface R18:** $R_{18} = -29.796$ (where $i = 18$), $a = 1.00000e+00$, $b = 0.00000e+00$, $c = 0.00000e+00$, $d = 0.00000e+00$, $e = 0.00000e+00$, $f = 0.00000e+00$, $t = 0.00000e+00$. **Surface R19:** $R_{19} = 6.222$ (where $i = 19$), $a = 1.00000e+00$, $b = 0.00000e+00$, $c = 0.00000e+00$, $d = 0.00000e+00$, $e = 0.00000e+00$, $f = 0.00000e+00$, $t = 0.00000e+00$. **Surface R20:** $R_{20} = -103.294$ (where $i = 20$), $a = 1.00000e+00$, $b = 0.00000e+00$, $c = 0.00000e+00$, $d = 0.00000e+00$, $e = 0.00000e+00$, $f = 0.00000e+00$, $t = 0.00000e+00$. **Surface R21:** $R_{21} = -18.173$ (where $i = 21$), $a = 1.00000e+00$, $b = 0.00000e+00$, $c = 0.00000e+00$, $d = 0.00000e+00$, $e = 0.00000e+00$, $f = 0.00000e+00$, $t = 0.00000e+00$. **Surface R22:** $R_{22} = 21.609$ (where $i = 22$), $a = 1.00000e+00$, $b = 0.00000e+00$, $c = 0.00000e+00$, $d = 0.00000e+00$, $e = 0.00000e+00$, $f = 0.00000e+00$, $t = 0.00000e+00$. **Surface R23:** $R_{23} = -56.334$ (where $i = 23$), $a = 1.00000e+00$, $b = 0.00000e+00$, $c = 0.00000e+00$, $d = 0.00000e+00$, $e = 0.00000e+00$, $f = 0.00000e+00$, $t = 0.00000e+00$. **Surface R24:** $R_{24} = -19.368$ (where $i = 24$), $a = 1.00000e+00$, $b = 0.00000e+00$, $c = 0.00000e+00$, $d = 0.00000e+00$, $e = 0.00000e+00$, $f = 0.00000e+00$, $t = 0.00000e+00$. **Surface R25:** $R_{25} = -9.154$ (where $i = 25$), $a = 1.00000e+00$, $b = 0.00000e+00$, $c = 0.00000e+00$, $d = 0.00000e+00$, $e = 0.00000e+00$, $f = 0.00000e+00$, $t = 0.00000e+00$. **Surface R26:** $R_{26} = -35.784$ (where $i = 26$), $a = 1.00000e+00$, $b = 0.00000e+00$, $c = 0.00000e+00$, $d = 0.00000e+00$, $e = 0.00000e+00$, $f = 0.00000e+00$, $t = 0.00000e+00$. **Surface R27:** $R_{27} = 7.883$ (where $i = 27$), $a = 1.00000e+00$, $b = 0.00000e+00$, $c = 0.00000e+00$, $d = 0.00000e+00$, $e = 0.00000e+00$, $f = 0.00000e+00$, $t = 0.00000e+00$. **Surface R28:** $R_{28} = 7.084$ (where $i = 28$), $a = 1.00000e+00$, $b = 0.00000e+00$, $c = 0.00000e+00$, $d = 0.00000e+00$, $e = 0.00000e+00$, $f = 0.00000e+00$, $t = 0.00000e+00$.
30. **Surface R29:** $R_{29} = 1.00000e+00$, $a = 1.00000e+00$, $b = 0.00000e+00$, $c = 0.00000e+00$, $d = 0.00000e+00$, $e = 0.00000e+00$, $f = 0.00000e+00$, $t = 0.00000e+00$. **Surface R30:** $R_{30} = 1.00000e+00$, $a = 1.00000e+00$, $b = 0.00000e+00$, $c = 0.00000e+00$, $d = 0.00000e+00$, $e = 0.00000e+00$, $f = 0.00000e+00$, $t = 0.00000e+00$. **Surface R31:** $R_{31} = 1.00000e+00$, $a = 1.00000e+00$, $b = 0.00000e+00$, $c = 0.00000e+00$, $d = 0.00000e+00$, $e = 0.00000e+00$, $f = 0.00000e+00$, $t = 0.00000e+00$.
35. **Shape of Aspheric Surface:** R_3 (the first aspherical element E1) and R_4 (the second aspherical element E2) which perform the function of magnifying the image or magnification have their reference axes in coincidence at the optical center thereof, which are positioned in front of the first optical element E1 and the second optical element E2, respectively. $a = 1.29771e+01$, $b = -1.91952e+01$, $c = 2.50000e+01$, $d = -5.3585e-05$, $e = 0.00000e+00$, $f = 0.00000e+00$, $t = 2.14047e-04$, $C_{03} = 2.44891e-08$, $C_{12} = 2.05128e-05$, $C_{21} = 1.18194e-05$, $C_{30} = 1.18194e-05$, $C_{40} = 1.53466e-03$, $C_{50} = 5.33084e-04$, $C_{60} = 1.13391e-03$, $C_{70} = -2.45084e-06$, $C_{80} = -2.01069e-04$, $C_{90} = 1.53466e-03$, $C_{100} = 1.13391e-03$, $C_{110} = -2.45084e-06$, $C_{120} = -2.01069e-04$, $C_{130} = 1.53466e-03$, $C_{140} = 1.13391e-03$, $C_{150} = -2.45084e-06$, $C_{160} = -2.01069e-04$, $C_{170} = 1.53466e-03$, $C_{180} = 1.13391e-03$, $C_{190} = -2.45084e-06$, $C_{200} = -2.01069e-04$, $C_{210} = 1.53466e-03$, $C_{220} = 1.13391e-03$, $C_{230} = -2.45084e-06$, $C_{240} = -2.01069e-04$, $C_{250} = 1.53466e-03$, $C_{260} = 1.13391e-03$, $C_{270} = -2.45084e-06$, $C_{280} = -2.01069e-04$, $C_{290} = 1.53466e-03$, $C_{300} = 1.13391e-03$, $C_{310} = -2.45084e-06$, $C_{320} = -2.01069e-04$, $C_{330} = 1.53466e-03$, $C_{340} = 1.13391e-03$, $C_{350} = -2.45084e-06$, $C_{360} = -2.01069e-04$, $C_{370} = 1.53466e-03$, $C_{380} = 1.13391e-03$, $C_{390} = -2.45084e-06$, $C_{400} = -2.01069e-04$, $C_{410} = 1.53466e-03$, $C_{420} = 1.13391e-03$, $C_{430} = -2.45084e-06$, $C_{440} = -2.01069e-04$, $C_{450} = 1.53466e-03$, $C_{460} = 1.13391e-03$, $C_{470} = -2.45084e-06$, $C_{480} = -2.01069e-04$, $C_{490} = 1.53466e-03$, $C_{500} = 1.13391e-03$, $C_{510} = -2.45084e-06$, $C_{520} = -2.01069e-04$, $C_{530} = 1.53466e-03$, $C_{540} = 1.13391e-03$, $C_{550} = -2.45084e-06$, $C_{560} = -2.01069e-04$, $C_{570} = 1.53466e-03$, $C_{580} = 1.13391e-03$, $C_{590} = -2.45084e-06$, $C_{600} = -2.01069e-04$, $C_{610} = 1.53466e-03$, $C_{620} = 1.13391e-03$, $C_{630} = -2.45084e-06$, $C_{640} = -2.01069e-04$, $C_{650} = 1.53466e-03$, $C_{660} = 1.13391e-03$, $C_{670} = -2.45084e-06$, $C_{680} = -2.01069e-04$, $C_{690} = 1.53466e-03$, $C_{700} = 1.13391e-03$, $C_{710} = -2.45084e-06$, $C_{720} = -2.01069e-04$, $C_{730} = 1.53466e-03$, $C_{740} = 1.13391e-03$, $C_{750} = -2.45084e-06$, $C_{760} = -2.01069e-04$, $C_{770} = 1.53466e-03$, $C_{780} = 1.13391e-03$, $C_{790} = -2.45084e-06$, $C_{800} = -2.01069e-04$, $C_{810} = 1.53466e-03$, $C_{820} = 1.13391e-03$, $C_{830} = -2.45084e-06$, $C_{840} = -2.01069e-04$, $C_{850} = 1.53466e-03$, $C_{860} = 1.13391e-03$, $C_{870} = -2.45084e-06$, $C_{880} = -2.01069e-04$, $C_{890} = 1.53466e-03$, $C_{900} = 1.13391e-03$, $C_{910} = -2.45084e-06$, $C_{920} = -2.01069e-04$, $C_{930} = 1.53466e-03$, $C_{940} = 1.13391e-03$, $C_{950} = -2.45084e-06$, $C_{960} = -2.01069e-04$, $C_{970} = 1.53466e-03$, $C_{980} = 1.13391e-03$, $C_{990} = -2.45084e-06$, $C_{1000} = -2.01069e-04$, $C_{1010} = 1.53466e-03$, $C_{1020} = 1.13391e-03$, $C_{1030} = -2.45084e-06$, $C_{1040} = -2.01069e-04$, $C_{1050} = 1.53466e-03$, $C_{1060} = 1.13391e-03$, $C_{1070} = -2.45084e-06$, $C_{1080} = -2.01069e-04$, $C_{1090} = 1.53466e-03$, $C_{1100} = 1.13391e-03$, $C_{1110} = -2.45084e-06$, $C_{1120} = -2.01069e-04$, $C_{1130} = 1.53466e-03$, $C_{1140} = 1.13391e-03$, $C_{1150} = -2.45084e-06$, $C_{1160} = -2.01069e-04$, $C_{1170} = 1.53466e-03$, $C_{1180} = 1.13391e-03$, $C_{1190} = -2.45084e-06$, $C_{1200} = -2.01069e-04$, $C_{1210} = 1.53466e-03$, $C_{1220} = 1.13391e-03$, $C_{1230} = -2.45084e-06$, $C_{1240} = -2.01069e-04$, $C_{1250} = 1.53466e-03$, $C_{1260} = 1.13391e-03$, $C_{1270} = -2.45084e-06$, $C_{1280} = -2.01069e-04$, $C_{1290} = 1.53466e-03$, $C_{1300} = 1.13391e-03$, $C_{1310} = -2.45084e-06$, $C_{1320} = -2.01069e-04$, $C_{1330} = 1.53466e-03$, $C_{1340} = 1.13391e-03$, $C_{1350} = -2.45084e-06$, $C_{1360} = -2.01069e-04$, $C_{1370} = 1.53466e-03$, $C_{1380} = 1.13391e-03$, $C_{1390} = -2.45084e-06$, $C_{1400} = -2.01069e-04$, $C_{1410} = 1.53466e-03$, $C_{1420} = 1.13391e-03$, $C_{1430} = -2.45084e-06$, $C_{1440} = -2.01069e-04$, $C_{1450} = 1.53466e-03$, $C_{1460} = 1.13391e-03$, $C_{1470} = -2.45084e-06$, $C_{1480} = -2.01069e-04$, $C_{1490} = 1.53466e-03$, $C_{1500} = 1.13391e-03$, $C_{1510} = -2.45084e-06$, $C_{1520} = -2.01069e-04$, $C_{1530} = 1.53466e-03$, $C_{1540} = 1.13391e-03$, $C_{1550} = -2.45084e-06$, $C_{1560} = -2.01069e-04$, $C_{1570} = 1.53466e-03$, $C_{1580} = 1.13391e-03$, $C_{1590} = -2.45084e-06$, $C_{1600} = -2.01069e-04$, $C_{1610} = 1.53466e-03$, $C_{1620} = 1.13391e-03$, $C_{1630} = -2.45084e-06$, $C_{1640} = -2.01069e-04$, $C_{1650} = 1.53466e-03$, $C_{1660} = 1.13391e-03$, $C_{1670} = -2.45084e-06$, $C_{1680} = -2.01069e-04$, $C_{1690} = 1.53466e-03$, $C_{1700} = 1.13391e-03$, $C_{1710} = -2.45084e-06$, $C_{1720} = -2.01069e-04$, $C_{1730} = 1.53466e-03$, $C_{1740} =$

R 7: a = 6.95459e+00 b = -9.77460e+00 t = 4.22976e+01
 C₀₃ = 1.48091e-04 C₂₁ = 1.42273e-03 C₄₂ = 1.05421e-08
 C₀₄ = 2.36193e-05 C₂₂ = 4.19020e-05 C₄₀ = 1.80643e-04

5 R 8: a = 2.61262e+01 b = 1.59224e+01 t = -22.2220e+01
 C₀₃ = 4.014325e-05 C₂₁ = 4.47240e-04
 C₀₄ = 3.20699e-06 C₂₂ = 3.07287e-05 C₄₀ = 1.58223e-05
 C₄₂ = 1.03991e-08 C₄₄ = 1.03991e-08

In Fig. 10, the first surface R1 is a stop that is the entrance pupil. A first optical element B1 is constructed with a

10 second surface R2 (refracting entrance surface), six curved inner reflecting surfaces R3 through R8 and a ninth surface R9 (refracting exit surface) arranged on one block. A second optical element B2 is constructed with a number of lenses with ten coaxial refracting surfaces R10 through R19. A third optical element B3 is constructed with a number of lenses with nine coaxial refracting surfaces R20 through R28. A twenty ninth surface R29 is the image plane coincident with the image receiving surface of an image pickup device such as a CCD.

15 The present embodiment provides a so-called 3-unit zoom lens. The stop R1 and the first optical element B1 constitute a first lens unit. The second optical element B2 constitutes a second lens unit. The third optical element B3 constitutes a third lens unit. Of these, the second and third lens units constitute a zoom section and move in differential relation to vary the focal length.

20 Next, the function of forming an image with an object at infinity is described. A light beam that has passed through the stop R1 enters the first optical element B1. In the interior of the first optical element B1, the light beam is refracted by the second surface R2, then reflected from the third surface R3, the fourth surface R4, the fifth surface R5, the sixth surface R6, the seventh surface R7 and the eighth surface R8 and then refracted by the ninth surface R9, exiting from the first optical element B1. During this time, the light beam is once focused to form an intermediate image in the neighborhood of the fourth surface R4. Further, a second image is formed in the space between the first optical element B1 and the second optical element B2.

25 The light beam then enters the second optical element B2. In the interior of the second optical element B2, the light beam is refracted by the surfaces R10 through R19 and then exits therefrom. At this time, the principal ray of the light beam is focused behind the nineteenth surface R19 to form a pupil image, and a tenth surface R20 is the young exit surface.

30 Next, the light beam that has exited from the second optical element B2 enters the third optical element B3. In the interior of the third optical element B3, the light beam is refracted by the surfaces R20 through R28 and exits therefrom, not reaching the twenty ninth surface or plane R29 on which the final image is formed. In other affection and decentered.

35 Next, the operation of varying the image magnification is described. The first optical element B1 remains stationary during zooming. The second optical element B2 first moves to the minus direction in the Z-axis as zooming goes from the wide-angle end toward the telephoto end, and then to the plus direction in the Z-axis. The third optical element B3 simultaneously moves to the minus direction in the Z-axis. The image plane or the twenty ninth surface R29 does not

move during zooming and the stop R1 and the second optical element B2 have a positive overall effective power and the By zooming from the wide-angle end to the telephoto end, the separation between the first optical element B1 and the second optical element B2 first narrows and then widens, the separation between the second optical element B2 and the third optical element B3 narrows, and the separation between the third optical element B3 and the image plane R29 widens. Also, the length of the optical path of the entire system from the first surface R1 to the image plane R29 is

40 kept constant throughout the entire zooming range. And so far, the light beam is converging and then refracted in exiting from the lens. In the present embodiment, the entering and exiting reference axes of the first optical element B1 are parallel with each other and oriented to the same direction. The second optical element B2 and the third optical element B3 which perform the function of varying the image magnification have their reference axes in coincidence with the optical axes thereof, which are common with each other. The entering and exiting reference axes of each of the second and third optical elements B2 and B3 are oriented to the same direction. The light beam is refracted at the ninth surface R9.

45 The lateral aberrations of the zoom optical system of the present embodiment are shown in the graphs of Figs. 11, 12 and 13. As can be seen from the figure, the third optical element B3 finally forms an image on the twenty ninth surface R29.

For the focusing purposes, the stop R1 and the first optical element B1 are moved in unison to the Z-axis to suit to

50 some different object distances. Reference axis and the exiting reference axis are oriented to the same direction.

An advantage of the present embodiment arises from the facts that the stop R1 is disposed on the object side of the zoom optical system and that two images of an object are formed in the interior of the first optical element B1 and behind the first optical element B1. By this arrangement, the effective diameter of each of the surfaces of the first optical element B1 is shortened. This leads to minimize the dimension in the X axis. The optical element of compact form is

55 thus obtained and the graphs of the lateral aberrations of such a optical system in the wide-angle end (W), a middle (M) and a telephoto end (T) are given. Another advantage arises from the fact that the first optical element B1 is provided with a plurality of inner reflecting surfaces which are given proper refractive powers and arranged in decentered relation. This allows the optical path to be bent to a desired shape without having to mutilate the light beam in passing through the zoom optical system. The total length in the Z direction is thus shortened as are considered by good balance in each of the conventional

Yet another advantage arising from the fact that the first optical element B1 has its reflecting surfaces formed on a rigid transparent body is that the reflecting surfaces can be positioned in a uniform tolerance (assembling tolerance) which greatly affects the optical performance. The optical system thus little suffers any loss of positioning accuracy with aging.

Further, the zoom optical system is made up by employing two different types of optical elements in good combination, one of which has a plurality of reflecting surfaces formed in unison and the other of which is constructed with the coaxial refracting surfaces (coaxial optical element). As compared with the case where the zoom optical system is constructed only with the reflecting surfaces arranged in decentered relation, the produced amount of decentering aberrations is more suppressed by having the coaxial optical element made to share the refractive power. The use of the optical element which is composed of coaxial refracting spherical surfaces facilitates the easiness of correcting all aberrations.

Furthermore, such an optical element of coaxial refracting spherical surfaces is easy to manufacture.

Although the foregoing embodiments have been described in connection with the optical element of reflecting surfaces on the one block which is fixed and the coaxial parts which move to effect zooming, variations may be made by fixing the coaxial parts and moving the optical element of reflecting surfaces on the one block to effect zooming. An example of such a variation is described below.

(Embodiment 4)

Second Optical Element B2

Fig. 14 shows sectional views in the YZ plane of an embodiment 4 of the zoom optical system according to the invention. This embodiment is applied to the optical system for use in picking up an image and provides a 3-component zoom lens whose range is about 3. The numerical data for this lens are shown below.

		W	M	T
	Horizontal Semifield	26.0	18.0	9.2
	Vertical Semifield	20.0	13.6	6.9
	Aperture Diameter	2.0	2.5	3.6

Image Size in mm: (H x V) = 4.8 x 3.6

	Optics Size at W: (XxYxZ) = 13.6 x 95.6 x 36.9					
1	30.94	56.28	0.00	6.10	R	
2	30.94	56.38	0.00	1.50	7.38329	R
3	30.93	51.95	0.00	9.10	R	
4	30.94	52.06	0.00	2.76	7.67729	R
5	30.94	50.82	0.00	3.20	7.70326	R
6	30.94	58.32	0.00	1.10	R	
7	30.94	58.32	0.00	1.50	1.059561	R
8	30.94	58.62	0.00	1.00	1.09446	R
9	30.94	51.5874	0.00	0.00	R	

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	i	Yi	Zi(W)	θ_i	Di	Ndi	vdi	Sur.
First Optical Element B1:								
5	1	0.00	0.00	0.00	1.00	1.49700	81.61	R (Right side angle and field stop)
	2	0.00	1.00	0.00	3.00	1		R
	3	0.00	4.00	0.00	Var.	1		Stop
Second Optical Element B2:								
10	4	0.00	-6.00	0.00	13.00	1.58312	59.37	R
	5	0.00	-19.00	-34.00	9.00	1.58312	59.37	L
15	6	-8.34	15.63	-19.00	9.00	1.58312	59.37	L
	7	-12.84	23.42	0.00	9.00	1.58312	59.37	L
	8	-17.34	15.63	-15.00	9.00	1.58312	59.37	L
20	9	-25.14	20.13	-30.00	12.00	1.58312	59.37	L
	10	-25.14	-8.13	0.00	0.00	1.58312	59.37	R
Third Optical Element B3:								
25	10	-25.14	8.13	0.00	2.00	1.67032	32.07	R
	11	-25.14	-6.13	0.00	Var.	1.67032	32.07	R
Fourth Optical Element B4:								
30	12	-25.14	-2.03	0.00	7.00	1.58313	59.37	R
	13	-25.14	-9.03	-32.00	12.00	1.58313	59.37	L
35	14	-35.92	-3.77	-14.00	12.00	1.58313	59.37	L
	15	-42.98	-13.48	0.00	12.00	1.58313	59.37	L
	16	-50.03	-3.77	14.00	12.00	1.58313	59.37	L
40	17	-60.82	-9.03	-32.00	7.00	1.58313	59.37	L
	18	-60.82	-1.03	0.00	Var.	1		R
Fifth Optical Element B5 (Negative Lens):								
45	19	-60.82	5.03	0.00	8.00	1.58313	59.37	R
	20	-60.82	13.03	30.00	10.00	1.58313	59.37	R
50	21	-69.48	8.03	15.00	10.00	1.58313	59.37	L
	22	-74.48	16.69	0.00	10.00	1.58313	59.37	L
	23	-79.48	8.03	-15.00	10.00	1.58313	59.37	L
	24	-88.14	13.03	-30.00	8.00	1.58313	59.37	L
	25	-88.14	5.03	0.00	Var.	1		R
	26	-88.14	-6.32	0.00	1.80	1		I.P.
				D15	176.96	34.79	70.29	

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 Z(0M) = Zi(W) + 10.00
 Z(0C) = Zi(W) + 39.88
 Z(0C) up to R3 = Zi(W) + 16.55
 Z(0C) = Zi(W) + 50.00

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Surface 1: $R_1 = 50.000$
 Surface 2: $R_2 = -10.000$
 Surface 3: $R_3 = 10.000$
 Surface 4: $R_4 = -10.000$
 Surface 5: $R_5 = 10.000$
 Surface 6: $R_6 = -10.000$
 Surface 7: $R_7 = 10.000$
 Surface 8: $R_8 = -10.000$
 Surface 9: $R_9 = 10.000$
 Surface 10: $R_{10} = -3.796$
 Surface 11: $R_{11} = 113.237$
 Surface 12: $R_{12} = 96.928$
 Surface 13: $R_{13} = 10.281$
 Surface 14: $R_{14} = 168.222$
 Surface 15: $R_{15} = 2.252 \times 10^{-7}$
 Surface 16: $R_{16} = 1.120 \times 10^{-8}$
 Surface 17: $R_{17} = 1.149 \times 10^{-9}$
 Surface 18: $R_{18} = 1.149 \times 10^{-10}$
 Surface 19: $R_{19} = 1.149 \times 10^{-11}$
 Surface 20: $R_{20} = 1.149 \times 10^{-12}$
 Surface 21: $R_{21} = 1.149 \times 10^{-13}$
 Surface 22: $R_{22} = 1.149 \times 10^{-14}$
 Surface 23: $R_{23} = 1.149 \times 10^{-15}$
 Surface 24: $R_{24} = 1.149 \times 10^{-16}$
 Surface 25: $R_{25} = 1.149 \times 10^{-17}$
 Surface 26: $R_{26} = 1.149 \times 10^{-18}$
 Surface 27: $R_{27} = 1.149 \times 10^{-19}$
 Surface 28: $R_{28} = 1.149 \times 10^{-20}$
 Surface 29: $R_{29} = 1.149 \times 10^{-21}$
 Surface 30: $R_{30} = 1.149 \times 10^{-22}$
 Surface 31: $R_{31} = 1.149 \times 10^{-23}$
 Surface 32: $R_{32} = 1.149 \times 10^{-24}$
 Surface 33: $R_{33} = 1.149 \times 10^{-25}$
 Surface 34: $R_{34} = 1.149 \times 10^{-26}$
 Surface 35: $R_{35} = 1.149 \times 10^{-27}$
 Surface 36: $R_{36} = 1.149 \times 10^{-28}$
 Surface 37: $R_{37} = 1.149 \times 10^{-29}$
 Surface 38: $R_{38} = 1.149 \times 10^{-30}$
 Surface 39: $R_{39} = 1.149 \times 10^{-31}$
 Surface 40: $R_{40} = 1.149 \times 10^{-32}$

	W	M	T
D 3	2.00	2.00	2.00
D11	8.16	5.68	3.02
D18	6.06	6.32	12.24
D25	11.35	14.09	22.67

10 R 1 + up to R11: $Zi(M) = Zi(W)$

15 Shape of Spherical Surface: $Zi(T) = Zi(W)$

R12 + up to R18: $Zi(M) = Zi(W) + 2.48$

20 R13 + up to R14: $Zi(T) = Zi(W) + 5.14 \times 10^{-20}$

R19 + up to R250: $Zi(M) = Zi(W) + 2.74 \times 10^{-19}$

25 R20: $Zi(T) = Zi(W) + 11.32 \times 10^{-18}$

R26: $Zi(M) = Zi(W) + 1.08002e-07$

30 R27: $Zi(T) = Zi(W) + 1.65502e-09$

R28: $Zi(M) = 3.5875e-09$

Shape of Spherical Surface:

35 R 8: $C_{00} = 87073e-03$ $C_{01} = -9.56928e-04$

R 1 Surface: $R_1 = 6e-06$ $C_{02} = 4.53546e-05$

R 2 Surface: $R_2 = 10.000$ $C_{03} = 1.42058e-06$

40 R 4 Surface: $R_4 = 10.000$ $C_{04} = 1.14932e-06$

R10 Surface: $R_{10} = -3.796$ $C_{05} = 1.14934e-06$

R11 Surface: $R_{11} = 113.237$ $C_{06} = 1.14936e-06$

R12 Surface: $R_{12} = 96.928$ $C_{07} = 1.14938e-06$

R18 Surface: $R_{18} = 10.281$ $C_{08} = 1.14940e-06$

45 R19 Surface: $R_{19} = 168.222$ $C_{09} = 1.14942e-06$

R25 Surface: $R_{25} = 2.252 \times 10^{-7}$ $C_{10} = 1.14944e-06$

$C_{11} = 1.14946e-06$

Shape of Aspheric Surface:

50 R 5: $a = \infty$ $b = \infty$ $t = 0.$ $C_{20} = -3.61721e-02$

R 6: $C_{02} = -2.77957e-02$ $C_{21} = 8.17518e-04$

$C_{03} = 2.17709e-04$ $C_{22} = -2.24283e-04$

$C_{04} = 4.81535e-05$ $C_{23} = -1.78732e-07$

$C_{05} = 4.84260e-07$ $C_{24} = -1.87310e-14$

40 R 6: $a = \infty$ $b = \infty$ $t = 0.$ $C_{25} = 9.54066e-09$

$C_{02} = -2.07844e-03$ $C_{26} = -3.13275e-02$

$C_{03} = -1.20110e-03$ $C_{27} = -7.31324e-03$

55 R 8: $a = \infty$ $b = \infty$ $t = 0.$ $C_{28} = 1.45746e-04$ and $C_{22} = -9.98634e-04$ and $C_{40} = 2.62001e-04$ very low order from the object side. A first optical element R1 is constructed with a flat surface R1 (refracting entrance surface of convex glass), a second

45 R7 (concave) and a third b = infinity R3 + 0.01 are in curved form or more. Reflected and decomposed, and a fourth surface R4 (refracting C02 = -2.65330e-02) is the body. The second surface R2 acts as a convex lens-like surface. C03 = 2.37808e-06; then C21 = -9.02645e-06 if all elements R2 is constructed with a flat surface R6 (refracting entrance C04 = 1.21344e-05) and a C22 = 8.82376e-05 and a C40 = 9.77118e-05 which are in curved form of inner reflection and reflected, and a refractive surface R9 (refracting exit surface of convex form) in one b-transparent body. The eighth

50 R 8: $a = \infty$ $b = \infty$ $t = 0.$ (a b-spherical lens t=0) surface. A third optical element R3 is in the form of a negative lens with a tenth surface C02 = 5.49968e-03 and C20 = 5.00091e-02 each other. A twelfth surface R12 is the final lens (convex) which will C03 = 1.23568e-03 and C21 = 6.67246e-03 (top deviation such as a C07)

55 The C04 = 5.38006e-05; R5, the C22 = 3.35556e-04; and C40 = 3.23857e-04 have a positive overall refractive power and move in tandem, constituting a first lens unit (front lens unit). The third optical element R3 has a negative refractive

55 R 9: $a = \infty$ $b = \infty$ $t = 0.$ (rear lens unit) which moves during zooming.

Assuming that an object is at infinity. A light beam coming from an C03 = 4.19848e-04 and C21 = 6.72125e-04 and the light beam is refracted passing through the first surface R1. Now, C04 = 6.12034e-05 is set. C22 = 3.47535e-05 at the C40 = -5.09619e-05 necessarily and then is refracted at the

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R13:	a = ∞	b = ∞	t = 0.	C ₀₂ = 2.26678e-02	C ₂₀ = 2.41426e-02	C ₀₃ = -2.57750e-04	C ₂₁ = 1.16383e-03	C ₀₄ = -2.40426e-05	C ₂₂ = -7.46204e-05	C ₄₀ = 2.82412e-05
R14:	a = ∞	b = ∞	t = 0.	C ₀₂ = -4.00972e-03	C ₂₀ = 7.14507e-03	C ₀₃ = -4.46529e-04	C ₂₁ = -2.31087e-03	C ₀₄ = -2.56127e-05	C ₂₂ = -1.36947e-04	C ₄₀ = -1.25987e-04
R15:	a = ∞	b = ∞	t = 0.	C ₀₂ = 1.41059e-02	C ₂₀ = 2.96468e-02	C ₀₃ = -8.17957e-05	C ₂₁ = 9.43283e-04	C ₀₄ = -1.06545e-05	C ₂₂ = -2.82343e-05	C ₄₀ = 4.45663e-05
R16:	a = ∞	b = ∞	t = 0.	C ₀₂ = -8.51071e-05	C ₂₀ = 2.53915e-02	C ₀₃ = 1.68862e-04	C ₂₁ = 3.65939e-03	C ₀₄ = 1.08096e-06	C ₂₂ = 1.80358e-04	C ₄₀ = 9.97536e-05
R17:	a = ∞	b = ∞	t = 0.	C ₀₂ = 1.32874e-02	C ₂₀ = 2.94218e-02	C ₀₃ = -6.81885e-05	C ₂₁ = 9.64816e-04	C ₀₄ = 1.70534e-05	C ₂₂ = 4.93143e-05	C ₄₀ = -1.51564e-06
R20:	a = ∞	b = ∞	t = 0.	C ₀₂ = -1.66195e-02	C ₂₀ = -1.97204e-02	C ₀₃ = -2.82112e-04	C ₂₁ = 8.70403e-05	C ₀₄ = -3.71423e-06	C ₂₂ = -7.20107e-06	C ₄₀ = -6.70241e-06
R21:	a = ∞	b = ∞	t = 0.	C ₀₂ = -2.13470e-02	C ₂₀ = -2.68230e-02	C ₀₃ = -7.85470e-04	C ₂₁ = 4.61286e-03	C ₀₄ = -1.61086e-04	C ₂₂ = -1.96712e-05	C ₄₀ = -6.34362e-05
R22:	a = ∞	b = ∞	t = 0.	C ₀₂ = -2.30872e-02	C ₂₀ = -2.69354e-02	C ₀₃ = -3.03473e-06	C ₂₁ = 1.13297e-03	C ₀₄ = -3.08514e-05	C ₂₂ = 5.26162e-05	C ₄₀ = 3.43593e-05
R23:	a = ∞	b = ∞	t = 0.	C ₀₂ = -2.42460e-02	C ₂₀ = -4.51798e-02	C ₀₃ = 3.73285e-04	C ₂₁ = 4.33871e-03	C ₀₄ = -1.89172e-04	C ₂₂ = 1.70543e-04	C ₄₀ = 3.82206e-06
R24:	a = ∞	b = ∞	t = 0.	C ₀₂ = -1.92202e-02	C ₂₀ = -2.60605e-02	C ₀₃ = 1.04217e-04	C ₂₁ = 3.77042e-04	C ₀₄ = 1.55696e-05	C ₂₂ = -2.50258e-05	C ₄₀ = -2.42690e-05

In Fig. 14, a first optical element B1 is in the form of a refractive lens with a first surface R1 and a second surface R2. A third surface R3 is a stop. A second optical element B2 is constructed with a fourth surface R4 (refracting entrance surface), five curved inner reflecting surfaces R5 through R9 and a tenth surface R10 (refracting exit surface) arranged on one block. A third optical element B3 is in the form of a refractive lens with a 10'-th surface R10' and an eleventh surface R11. Incidentally, the second and third optical elements B2 and B3 are cemented together at their adjoining surfaces R10 and R10'.

A fourth optical element B4 is constructed with a twelfth surface R12 (refracting entrance surface), five curved inner reflecting surfaces R13 through R17 and an eighteenth surface R18 (refracting exit surface) arranged on one block. A fifth optical element B5 is constructed with a nineteenth surface R19 (refracting entrance surface), five curved inner

reflecting surfaces R20 through R24 and a twenty fifth surface R25 (refracting exit surface) arranged on one block. A twenty sixth surface R26 is the image plane coincident with the image receiving surface of an image pickup device such as a CCD.

The present embodiment provides a so-called 3-component zoom lens. The first optical element B1, the stop R3, the second optical element B2 and the third optical element B3 constitute a first lens unit. The fourth optical element B4 constitutes a second lens unit. The fifth optical element B5 constitutes a third lens unit. Of these, the second and third lens units constitute a zoom section and vary their relative positions to vary the focal length.

Next, the function of forming an image with an object at infinity is described. A light beam that has passed through the first optical element B1 and the stop R3 successively, enters the second optical element B2. In the interior of the second optical element B2, the light beam is refracted by the fourth surface R4, then reflected from the fifth surface R5, the sixth surface R6, the seventh surface R7, the eighth surface R8 and the ninth surface R9 and then refracted by the tenth surface R10. The refracted light beam enters the third optical element B3 and is refracted by the eleventh surface R11, exiting from the third optical element B3. During this time, the light beam is focused to form an intermediate image in the neighborhood of the sixth surface R6. Further, a second image is formed in the space between the third optical element B3 and the fourth optical element B4.

The light beam then enters the fourth optical element B4. In the interior of the fourth optical element B4, the light beam is refracted by the twelfth surface R12, then reflected from the thirteenth surface R13, the fourteenth surface R14, the fifteenth surface R15, the sixteenth surface R16 and the seventeenth surface R17 and then refracted by the eighteenth surface R18. Then, the light beam exits from the fourth optical element B4. During this time, the light beam is focused to form an intermediate image in the space between the fourteenth surface R14 and the fifteenth surface R15. Further, the light beam forms a pupil in the neighborhood of the sixteenth surface R16.

Then, the light beam enters the fifth optical element B5. In the interior of the fifth optical element B5, the light beam is refracted by the nineteenth surface R19, then reflected from the twentieth surface R20, the twenty first surface R21, the twenty second surface R21, the twenty third surface R23 and the twenty fourth surface R24 and then refracted by the twenty fifth surface R25. The light beam thus exits from the fifth optical element B5. During this time, the light beam is focused to form an intermediate image in the neighborhood of the twenty first surface R21.

Finally, the light beam exiting from the fifth optical element B5 arrives at the twenty sixth surface or plane R26 on which the final image is formed.

Next, the operation of varying the image magnification is described. The first unit composed of the first optical element B1, the second optical element B2 and the third optical element B3 remains stationary during zooming. The fourth optical element B4 moves to the plus direction in the Z axis as zooming goes from the wide-angle end to the telephoto end. The fifth optical element B5 simultaneously moves to the plus direction in the Z axis. The image plane or the twenty sixth surface R26 does not move during zooming.

During zooming from the wide-angle end to the telephoto end, the separation between the third optical element B3 and the fourth optical element B4 narrows, the separation between the fourth optical element B4 and the fifth optical element B5 widens and the separation between the fifth optical element B5 and the image plane R26 widens. Also, the length of the optical path of the entire system from the first surface R1 to the image plane R29 becomes longer as zooming goes from the wide-angle end to the telephoto end.

In the present embodiment, the entering and exiting reference axes of each of the second, fourth and fifth optical elements B2, B4 and B5 are parallel with each other and oriented to opposite directions.

The lateral aberrations of the zoom optical system of the present embodiment are shown in the graphs of Figs. 15, 16 and 17.

For the focusing purposes, the first optical element B1 is moved to the Z axis to suit to different object distances.

An advantage of the present embodiment arises from the facts that the stop R3 is disposed adjacent to the entrance surface R1 at which a light beam first enters in the zoom optical system and that an image of an object is formed in the interior of each of the second, fourth and fifth optical elements B2, B4 and B5. By this arrangement, the effective diameter of each of the surfaces of these optical elements is shortened. This leads to minimize the dimension in the X axis. The optical element of compact form is thus obtained.

Another advantage arises from the fact that the second, fourth and fifth optical elements B2, B4 and B5 each are provided with a plurality of inner reflecting surfaces which are given proper refractive powers and arranged in decentered relation. This allows the light beam inside the zoom optical system to be folded to a desired shape without causing the light beam to be blocked off in any part. The total length in the Z direction is thus shortened.

Yet another advantage arising from the fact that the second, fourth and fifth optical elements B2, B4 and B5 each have its reflecting surfaces formed on a rigid transparent body is that the reflecting surfaces can be positioned in a uniform tolerance (assembling tolerance) which greatly affects the optical performance. The optical system thus little suffers any loss of positioning accuracy with aging.

Furthermore, the zoom optical system has its first optical element B1 constructed with coaxial refracting surfaces (in the form of a coaxial optical element). Therefore, the focusing mechanism becomes simpler in structure.

Another feature of the invention is that the entering reference axis of the first optical element B1 which does not

move during Zooming as in the above embodiments 1 to 4 may be inclined by a certain angle with respect to that plane which has so far contained all of the reference axes, that is, the YZ plane. By this arrangement, the degree of freedom for the form of cameras can be increased; reducing optical aberrations are produced by six rays of light which

Fig. 18 is a perspective view of a zoom optical system with the entering reference axis oriented to parallelism with the X axis. This optical system is derived from the first embodiment 1 by providing the space between the second surface R2 and the third surface R3 with an inner reflecting mirror R1;2 of flat shape inclined 45° to the YZ plane. The entering reference axis of the first optical element B1 is thus set up in parallel to the X axis.

In Fig. 18, a first optical element B1 remains stationary during zooming, so corresponding to the first unit of the 3-unit zoom optical system. It is to be noted that the first optical element B1 is shown by its reflecting surfaces along in

perspective view. A second optical element B2 and a third optical element B3 move in differential relation to vary the focal length, so constituting a zoom section. The second optical element B2 corresponds to the so-called variator, and the third optical element B3 corresponds to the so-called compensator or symmetry with regard to the ray of light.

The second and third optical elements B2 and B3 move on one common line (the aligned optical axis of these optical elements) in the YZ plane in Fig. 18. All the reference axes of the second and third optical elements B2 and B3 lie

on this line. The result is that surfaces of prisms and image lenses, popularly using the name are equivalent.

In this optical system, some of the reference axes within the first optical element B1 stationary during zooming, namely a reference axis A1;2 through a reference axis A1;8, must exist in the YZ plane. However, the others, i.e., a reference axis A0 from the object to the stop, and a reference axis A1;1 from the stop to the first reflecting surface R1;2 are not necessarily present in the plane of the reference axes (YZ plane) of having formed in one transparent body

other. In other words, the present embodiment employs the reflecting surface R1;2 for the purpose of deflecting the direction of the reference axis A0 entering from the direction of the X axis to the direction of the Z axis. In such a manner, the direction of a light beam leaving the zoom optical system can be determined freely when the reflecting surface R1;2 is disposed at an appropriate point in the neighborhood of the entrance surface R2 of the first reflective block and inclined by an appropriate angle to the YZ plane in which the later reference axes are contained. This leads to a possibility of increasing the degree of freedom for the design of cameras.

(Embodiment 5) system comprises a plurality of optical elements. The plurality of optical elements include a first optical element having two reflecting surfaces and a plurality of reflecting surfaces formed in a transparent body, being

Fig. 19 shows sectional views in the YZ plane of an embodiment 5 of the zoom-optical system according to the said invention. This embodiment is applied to the optical system for use in picking up an image and provides a 3-component zoom lens whose range is about 2. The numerical data for the embodiment 5 are shown below: centered above the two others, being arranged such that an incident light beam with the stop after being successively reflected from reflecting surfaces of the plurality of surface mirrors, and a third optical element composed of a plurality of coaxial reflecting surfaces. In the zoom optical system, an image of an object is formed at W with a magnification of M₁ through the plurality of optical elements. And zooming is effected by varying relative positions of at least two optical elements of said plurality of optical elements.

Optical Element	W	M ₁	M ₂
Horizontal Semicfield	19.1	13.7	9.8
Vertical Semicfield	14.5	10.4	7.4
Aperture Diameter	1.60	1.80	2.10

Claims

1. A zoom optical system comprising:

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a plurality of optical elements including:

- a) a first optical element and **Image Size in mm: (HxV)=4.0x3.0** a plurality of reflecting surfaces formed in a transparent body, being arranged such that a light beam enters an inside of the transparent body, from one of the two refracting surfaces, **Optics Size at W: (XxYxZ)=10.0x30.0x49.9** the plurality of reflecting surfaces, exits from the other of the two refracting surfaces, and/or
- b) a second optical element having a plurality of surface mirrors, integrally formed and desirably relative to one another, being arranged such that an incident light beam exits therefrom after being successively reflected from reflecting surfaces of the plurality of surface mirrors, and
- c) a third optical element composed of a plurality of coaxial reflecting surfaces,

wherein an image of an object is formed through said plurality of optical elements, and zooming is effected by varying relative positions of at least two optical elements of said plurality of optical elements.

55. A zoom optical system according to claim 1, wherein a stop is disposed on a light entrance side of said zoom optical system, or adjacent to a light entrance surface at which a light beam first enters.

3. A zoom optical system according to claim 1 or 2, wherein each of said at least two optical elements of which relative positions are varied has an entering reference axis and an exiting reference axis in parallel to each other.

	Yi	Zi(W)	Wd	Di	Ndi	vdi	Sur.
First Lens Unit							
1	0.00	0.00	0.00	2.00	1		Stop
First Optical Element B1:							
2	0.00	2.00	0.00	2.00	1.74400	44.70	R
3	0.00	4.00	0.00	8.00	1		R
Second Optical Element B2:							
4	0.00	12.00	30.00	12.00	1		L
5	-10.39	6.00	30.00	10.00	1		L
Third Optical Element B3:							
6	-10.39	16.00	0.00	2.00	1.75500	27.60	R
7	-10.39	18.00	0.00	Var.	1		R
Second Lens Unit:							
Fourth Optical Element B4:							
8	-10.39	36.98	0.00	2.00	1.71766	46.92	R
9	-10.39	38.98	0.00	7.00	1		R
Fifth Optical Element B5:							
10	-10.39	45.98	45.00	12.00	1		L
11	-22.39	45.98	45.00	Var.	1		L
Third Lens Unit:							
Sixth Optical Element B6:							
12	-22.39	34.18	0.00	2.00	1.48994	68.59	R
13	-22.39	32.18	0.00	Var.	1		R
14	-22.39	18.85	0.00		1		I.P.
C ₁ =-0.03554e-02							
C ₂ =-1.13207e-02							
C ₃ =-6.20162e-03							
C ₄ =-3.46318e-03							
		W	M	T			
	D7	18.98	8.71	1.00			
	D11	411.80	15.25	20.00			
	D14	13.33	13.33	13.33			

R 1 + up to R 7: Zi(M) = Zi(W) + 13.73

$$Z(T) = Z(W) \pm 26.18$$

Oxygen consumption

50 R 8 + up to R11: $Z_i(M) = Z_i(W) + 3.46$

$$Zi(T) = Zi(W) + 8.20$$

$Z(1) = Z(W) + 8.20$ (1000 m.s.m.)
 $Z(MN) = Z(W) + 6.20$ (1000 m.s.m.)

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R12 up to **R13**: $Zi(T) = Zi(W) + 8.20 \text{ mm}$. The form of a solenoid lens with a large sagittal radius and a second substrate
R13: $Zi(M) = Zi(W)$: top. A second optical element M2 is constructed with a fourth surface R6, polarizing
 lens, and $Zi(T) = Zi(W)$ lens reflecting surfaces R9 through R9 and a tenth surface R10, (reflecting exit surface)
R14: arranged as in **R13**: $Zi(M) = Zi(W)$: optical element P8 is in the form of a refractive lens with a "G-d" surface H11 and an
 eleventh substrate $Zi(T) = Zi(W)$; finally, the second and third optical elements 132 and 133 are cemented together at their
 abutting surfaces R13 and H11.

R 2 Surface ($R_2 = 97.206$) conjugated with a twelfth surface R(12) (refracting entrance surface). Five curved inner reflecting surfaces R(13) through R(17) are on eighteenth surface R(18) (refracting exit surface) arranged on one block. A

R 3 Surface: $R_3 = -26.032$
 R 6 Surface: $R_6 = 11.385$
 R 7 Surface: $R_7 = 15.046$
 R 8 Surface: $R_8 = -159.987$
 5 R 9 Surface: $R_9 = 24.470$
 R12 Surface: $R_{12} = 1000.000$
 R13 Surface: $R_{13} = -85.375$

Shape of Aspheric Surface:

10	R 4: $a = 1.45475e+01$ $C_{03} = 8.63617e-04$ $C_{04} = 8.13611e-05$	$b = -5.77853e+00$ $C_{21} = 1.60115e-03$ $C_{22} = 7.31698e-05$	$t = -2.42608e+01$ $C_{40} = -1.34827e-04$
15	R 5: $a = -9.91101e+01$ $C_{03} = 8.70976e-05$ $C_{04} = -1.72354e-04$	$b = 4.27960e+01$ $C_{21} = 1.68477e-04$ $C_{22} = -2.22388e-04$	$t = -1.14636e+01$ $C_{40} = -1.98849e-04$
20	R10: $a = 4.10898e+02$ $C_{03} = -1.57719e-04$ $C_{04} = 2.54948e-06$	$b = -2.06186e+01$ $C_{21} = 4.64176e-04$ $C_{22} = 1.89777e-05$	$t = 4.55596e+01$ $C_{40} = 8.72541e-07$
25	R11: $a = -1.26094e+02$ $C_{03} = 9.65477e-05$ $C_{04} = -5.69335e-06$	$b = 2.55428e+01$ $C_{21} = 6.18718e-05$ $C_{22} = 2.19389e-05$	$t = 4.44452e+01$ $C_{40} = 8.07381e-06$

In Fig. 19, the first surface R1 is a stop that is the entrance pupil. A first optical element B1 is a refractive lens formed with a second surface R2 and a third surface R3. A second optical element B2 is formed with a reflecting fourth surface R4 and a reflecting fifth surface R5 each as a surface mirror in unison on one member. A third optical element B3 is a refractive lens formed with a sixth surface R6 and a seventh surface R7. A fourth optical element B4 is a refractive lens formed with an eighth surface R8 and a ninth surface R9. A fifth optical element B5 is formed with a reflecting tenth surface R10 and a reflecting eleventh surface R11 each as a surface mirror in unison on one member. A sixth optical element B6 is a refractive lens formed with a twelfth surface R12 and a thirteenth surface R13. A fourteenth surface R14 is the image plane coincident at the image receiving surface of an image pickup device such as a CCD.

The first to third optical elements B1, B2 and B3 constitute a first lens unit. The fourth and fifth optical elements B4 and B5 constitute a second lens unit. The sixth optical element B6 constitutes a third lens unit. Of these, the first and second lens units constitute a zoom section and vary their relative positions to vary the focal length.

Next, the function of forming an image with an object at infinity is described. A light beam that has passed through the stop R1 and the first optical element B1 successively enters the second optical element B2. In the interior of the second optical element B2, the light beam is reflected from the fourth surface R4 and the fifth surface R5 and exits from the second optical element B2. During this time, the light beam forms an intermediate image in the neighborhood of the fifth surface R5. Then, the light beam passes through the third optical element B3.

The light beam then passes through the fourth optical element B4 and enters the fifth optical element B5. In the interior of the fifth optical element B5, the light beam is reflected from the tenth surface R10 and the eleventh surface R11 and then exits from the fifth optical element B5. During this time, the light beam forms a pupil in the space between the tenth surface R10 and the eleventh surface R11.

Then, the light beam passes through the sixth optical element B6 and forms a final image on the fourteenth surface R14.

Next, the operation of varying the image magnification is described. During zooming from the wide-angle end to the telephoto end, the first lens unit (the first to third optical elements B1, B2 and B3) moves to the plus direction in the Z axis. The second lens unit (the fourth and fifth optical elements B4 and B5), too, simultaneously moves to the plus direction in the Z axis. The sixth optical element B6 and the fourteenth surface R14 that is the image plane do not move during zooming.

By zooming from the wide-angle end to the telephoto end, the separation between the third optical element B3 and the fourth optical element B4 narrows and the separation between the fifth optical element B5 and the sixth optical element B6 widens. The separation between the sixth optical element B6 and the image plane R14 does not vary. Also, the length of the optical path of the entire system from the first surface R1 to the image plane R14 varies, becoming ever shorter as zooming goes from the wide-angle end to the telephoto end.

In the present embodiment, the entering and exiting reference axes of the second optical element B2 are parallel

with each other and oriented to the same direction. The entering and exiting reference axes of the fifth optical element B5 are parallel with each other and oriented to opposite directions.

The lateral aberrations of the zoom optical system of the present embodiment are shown in the graphs of Figs. 20, 21 and 22.

For the focusing purposes, either the second lens unit (the fourth and fifth optical elements B4 and B5) or the third lens unit (the sixth optical element B6) moves to suit to different object distances.

An advantage of the present embodiment arises from the facts that the stop R1 is disposed on the object side of the zoom optical system and that an object image is formed in the interior of the second optical element B2. By this arrangement, the effective diameter of each of the surfaces of the second optical element B2 and those that follow is shortened. This leads to minimize the dimension in the X axis. The optical elements of compact form are thus obtained.

Another advantage arises from the fact that the second and fifth optical elements B2 and B5 each are provided with a plurality of reflecting surfaces which are given proper refractive powers and arranged in decentered relation. This allows the light beam inside the zoom optical system to be folded to a desired shape without causing the light beam to be blocked off in any part. The total length in the Z direction is thus shortened.

Yet another advantage arising from the fact that the second and fifth optical elements B2 and B5 each have its two surface mirrors formed in unison on one member is that the reflecting surfaces can be positioned in a uniform tolerance (assembling tolérance) which greatly affects the optical performance. The optical system thus little suffers any loss of positioning accuracy with aging.

Further, the zoom optical system of the present embodiment is made up by employing a number of optical elements of two types in good combination, one of which has a plurality of reflecting surfaces formed in unison and the other of which is constructed with the coaxial refracting surfaces (coaxial optical element). As compared with the case where the zoom optical system is constructed only with the reflecting surfaces arranged in decentered relation, therefore, the amount of decentering aberrations is more suppressed by having the coaxial optical element made to share the refractive power. The use of the optical element which is composed of coaxial refracting spherical surfaces facilitates the easiness of correcting all aberrations.

Furthermore, such an optical element of coaxial refracting spherical surfaces is easy to manufacture.

It is to be noted that, since, in the present embodiment, the sixth optical element B6 is a refractive lens, the direction of the exiting reference axis from the sixth optical element B6 is the same as the direction of the entering reference axis to the sixth optical element B6. However, it is to be understood that the direction and angle of the exiting reference axis are not confined as such. For example, the space between the sixth optical element B6 and the image plane R14 may be provided with an additional mirror inclined 45° to the YZ plane so that the exiting reference axis is bent to the perpendicular direction (parallel to the X axis) to the paper.

Also, for the entering reference axis to the optical system, a mirror, for example, may be disposed on the object side of the stop R1 and inclined 45° to the YZ plane so that the reference axis enters from the perpendicular direction (parallel to the X axis) to the paper. The use of such a mirror can even more increase the degree of freedom for the design of cameras.

Of the above-described embodiments, the embodiments 1 to 4 each provide a zoom optical system comprising a plurality of optical elements including an optical element having two refracting surfaces and a plurality of reflecting surfaces formed in a transparent body, being arranged such that a light beam enters an inside of the transparent body from one of the two refracting surfaces and, after being successively reflected from the plurality of reflecting surfaces, exits from the other of the two refracting surfaces, and an optical element composed of a plurality of coaxial refracting surfaces, wherein an image of an object is formed through the plurality of optical elements, and zooming is effected by varying relative positions of at least two optical elements of the plurality of optical elements. The embodiment 5 provides a zoom optical system comprising a plurality of optical elements including an optical element having a plurality of surface mirrors integrally formed and decentered relative to one another, being arranged such that an incident light beam exits therefrom after being successively reflected from reflecting surfaces of the plurality of surface mirrors, and an optical element composed of a plurality of coaxial refracting surfaces, wherein an image of an object is formed through the plurality of optical elements, and zooming is effected by varying relative positions of at least two optical elements of the plurality of optical elements.

Besides these, according to the invention, the fourth optical element B4 and/or the fifth optical element B5 in the embodiment 4 may be otherwise constructed with a plurality of surface mirrors decentered from one another and made up in unison, such that the entering light beam repeats reflection from the successive surface mirrors, before it exits. In this case, there is produced an advantage of reducing the weight of the zoom optical system.

Also, in the invention, for the optical element which contributes to a variation of the focal length, the direction of zooming movement is not necessarily parallel to the direction of the entering reference axis to the zoom optical system. Depending on the situation of the design of the image pickup apparatus, the direction of zooming movement of the optical element may be changed to an angle of, for example, 30°, 45° or 60° with respect to the entering reference axis to the zoom optical system by inclining the exiting reference axis of the first optical element.

Next, another form of the zoom optical system will be described below.

When defining, as a reference axis ray, a ray of light which comes from an object, enters the zoom optical system, passes the center of a stop and reaches the center of a final image plane, defining, as an entering reference axis of each surface, each optical element or each lens unit; the reference axis ray which enters each surface, each optical element or each lens unit of the zoom optical system, defining, as an exiting reference axis of each surface, each optical element or each lens unit, the reference axis ray which exits from each surface, each optical element or each lens unit of the zoom optical system, defining, as a reference point, an intersection point of the entering reference axis and each surface, defining, as a direction of the entering reference axis and a direction of the exiting reference axis, directions in which the reference axis ray advances from an object side to an image side in the entering reference axis and the exiting reference axis, respectively, the zoom optical system comprises the stop, at least one off-axial optical element having an off-axial reflecting surface inclined with respect to the reference axis ray, and at least one coaxial optical element composed only of surfaces of revolution symmetry with respect to the reference axis ray, wherein zooming is effected by moving the at least one off-axial optical element and the at least one coaxial optical element.

In particular, the zoom optical system has the following features:

The off-axial optical element is an optical element having two refracting surfaces and one or more off-axial reflecting surfaces integrally formed in a transparent body.

The off-axial optical element is disposed immediately before and/or immediately behind the stop along the reference axis ray.

The stop moves in unison with the off-axial optical element which moves during zooming.

The coaxial optical element is a single lens.

The direction of the reference axis ray passing through the coaxial optical element is orthogonal or inclined to the direction of the reference axis ray passing through the stop.

Further, when defining, as a reference axis ray, a ray of light which comes from an object, enters the zoom optical system, passes the center of a stop and reaches the center of a final image plane, defining, as an entering reference axis of each surface, each optical element or each lens unit, the reference axis ray which enters each surface, each optical element or each lens unit of the zoom optical system, defining, as an exiting reference axis of each surface, each optical element or each lens unit, the reference axis ray which exits from each surface, each optical element or each lens unit of the zoom optical system, defining, as a reference point, an intersection point of the entering reference axis and each surface, defining, as a direction of the entering reference axis and a direction of the exiting reference axis, directions in which the reference axis ray advances from an object side to an image side in the entering reference axis and the exiting reference axis, respectively, the zoom optical system comprises, in order from an object side along the reference axis ray, a first off-axial optical element, the stop, a second off-axial optical element and a coaxial optical element, wherein zooming is effected by moving at least one of the first and second off-axis optical element and the coaxial optical element.

In particular, the zoom optical system has the following features.

Each of the first and second off-axial optical elements is an optical element having two refracting surfaces and two off-axial reflecting surfaces integrally formed in a transparent body.

The direction of the entering reference axis and the direction of the exiting reference axis of each of the first and second off-axial optical elements are parallel to each other.

The first off-axial optical element, the stop and the second off-axial optical element move in unison during zooming.

The first off-axial optical element, the second off-axial optical element and the coaxial optical element move independent of each other during zooming.

The direction of the entering reference axis and the direction of the exiting reference axis of each of the first and second off-axial optical elements are orthogonal to each other, and the first off-axial optical element, the stop and the second off-axial optical element move in unison during zooming.

The coaxial optical element is a negative lens.

Fig. 29 is a diagram of the basic design of an embodiment 6 of the zoom optical system according to the invention. A reference axis ray 12 passes at the center of the aperture opening of a stop 11 and arrives at the center of a final image plane 16. Optical elements 13 and 14 each have a reflecting surface (not shown) inclined to the reference axis ray 12. (The inclined reflecting surface to the entering reference axis is hereinafter called the "off-axial" reflecting surface. Also, the optical element having the off-axial reflecting surface is hereinafter called the "off-axial" optical element.) The first off-axial optical element 13 and the second off-axial optical element 14 are arranged along the reference axis ray 12 in this order from the object side.

A third optical element of revolution symmetry with respect to the reference axis ray 12 (or coaxial optical element) is disposed before the final image plane 16. The first off-axial optical element 13, the stop 11 and the second off-axial optical element 14 move in unison as a front lens unit 17, during zooming. The third optical element 15 simultaneously moves as a rear lens unit.

Here, the front lens unit 17 has a positive refractive power and the rear lens unit 15 has a negative refractive power. As a whole, they constitute a 2-unit zoom lens of plus-minus power arrangement, wherein the rear lens unit 15 bears

the function of varying the image magnification, while the front lens unit 17 compensates for the image shift.

The reference axis ray 12 passes at the center of aperture opening of the stop 11 and is refracted or reflected by the successive surfaces, finally arriving at the center of the final image plane 16. In the invention, the reference axis ray is used as being equivalent to the optical axis of the coaxial system. Although the reference axis ray has been defined as encountering the center of aperture opening of the stop and the center of the image plane, the invention is not confined to such a definition, provided that it is representative of the effective light beam of the optical system.

Fig. 30 shows the structure of the first off-axial optical element 13. Fig. 31 is a perspective view of the first off-axial optical element 13. The first optical element 13 is formed with two refracting surfaces 41 and 44 and two reflecting surfaces 42 and 43 in a transparent body. Incidentally, the reflecting surfaces 42 and 43 are coated by the vacuum evaporation technique or the like to form mirrors. The refracting surface 41 is an entrance surface, and the refracting surface 42 is an exit surface.

In the front lens unit 17 of an embodiment 6 of the invention, such optical elements as the first off-axis optical element 13 are arranged on either side of the stop 11 in symmetric relation. By this arrangement, the principal ray of any angular field is guided symmetrically in respect to the stop 11 at every station in the entire zooming range, thus producing an effect of canceling the decentering distortions by each other. This would be hardly obtained if the front lens unit 17 is constructed with one off-axial optical element. The use of the unified form of a number of surfaces like the first or second optical element 13 or 14 assures a higher positioning accuracy than when the individual surfaces are set up one after another, thus obviating the necessity of adjusting the positions and the inclinations. Also, there is no need to use a member for supporting the reflecting surfaces. Therefore, the number of parts is reduced.

Another advantage arises from the main contribution of the reflecting surfaces to the required refractive power for the optical element. This allows the refracting surfaces to have a greater degree of freedom. So, despite the desired refractive power being held, it becomes possible to suppress the produced amount of chromatic aberrations.

The present embodiment employs such optical elements in the zoom optical system with an advantage of obviating the necessity of using a positive lens and a negative lens in one unit for the purpose of correcting chromatic aberrations. So, the zoom optical system can be constructed with a smaller number of optical parts.

In the present embodiment, the off-axial optical element and the coaxial optical element which is constructed only with surfaces of revolution symmetry are used in combination. This leads to achieve a zoom optical system having a lens unit and the one negative lens is sufficient for the rear lens unit. Thus, three parts constitute the zoom optical system. Fig. 32 is a diagram of the basic design of an embodiment 7 of the Zoom optical system according to the invention. This embodiment differs from the embodiment 6 in the construction of the front lens unit. In Fig. 32, a first optical element 21 and a second optical element 22 corresponds to the first off-axial optical element 13 and the second off-axial optical element 14 of the embodiment 6, respectively. Even in the present embodiment, the first optical element 21, the stop 11 and the second optical element 22 constitute a front lens unit 24 of a 2-unit zoom optical system, and the third optical element 15 constitutes a rear lens unit 22 and 13 constitute a first lens unit 21. The fourth and fifth optical elements 24 and 25 constitute a second lens unit 22. The zooming method of the present embodiment is the same as that of the embodiment 6 and, in those, the first and second lens units 21 and 22 move in differential relation during zooming.

In the present embodiment, the first optical element 21 and the second optical element 22 each are arranged so that the entering direction of the reference axis ray is orthogonal to the exiting direction thereof, thus reducing the size of the front lens unit 24 in the z direction. Therefore, the total length in this direction becomes shorter than that of the embodiment 6. Incidentally, the direction of the reference axis ray passing through the stop 11 is orthogonal to the direction of the reference axis ray passing through the third optical element 15 in intermediate image in the zooming method of the embodiment 6. Further, the basic optical arrangement of the present embodiment is the same as that of the embodiment 6. The optical elements 21 and 22 are arranged on either side of the stop 11 in symmetric relation to correct decentering distortion in particular. The other effects are the same as in the embodiment 6. The surfaces 13 and 14 are the surfaces of revolution symmetry.

Fig. 33 is a diagram of the basic design of an embodiment 8 of the zoom optical system according to the invention. This embodiment resembles in construction with the embodiment 6, but differs from the embodiment 6 in a point that the front lens unit shown in Fig. 29 is divided into two parts with the result that the entire system comprises three units. These three units move in differential relation during zooming. That is, the first optical element 13 is used as a first lens unit, the stop 11 and the second optical element 14 as a second lens unit and the third optical element (coaxial optical element) 15 as a third lens unit. This produces an advantage of reducing the range of variation of decentering aberrations of the optical elements 13 and 14 during zooming.

Even in the present embodiment, the off-axial optical element and the coaxial optical element of only the surfaces of revolution symmetry are used in combination, thereby producing an advantage of achieving a zoom optical system with a smaller total number of parts. In the case of Fig. 33, two off-axial optical elements and one negative lens, that is, and three parts, are sufficient for constructing a 3-unit zoom optical system. The first optical element 13 and the middle optical element 14 are the surfaces of revolution symmetry.

The method of expressing the design parameters for the following numerical examples is fundamentally the same as that for the numerical examples of the embodiments 1 to 5, but different points are mentioned below.

The values of the coordinate of every surface are expressed in relation of the values for the wide-angle end. For the middle position and the telephoto end, the values are expressed by the differences from those of the wide-angle end.

Specifically, denoting the moved amounts from the wide-angle end (W) to the middle position (M) and the telephoto end (T) by "a" and "b", respectively, the following equations are obtained:

$$Z_i(M) = Z_i(W) + a$$

5

$$Z_i(T) = Z_i(W) + b,$$

where the sign of the "a" or "b" is positive when the surface moves to the plus direction, or negative when it moves to the minus direction. The ones of the separations D_i which vary with this movement are variable. So, their values for each 10 zooming station are listed together in another tabulation.

D_i is a scalar quantity representing the separation between the original points of the local coordinates for the i -th and $(i+1)$ st surfaces. N_{di} and v_{di} are respectively the refractive index and Abbe number of the medium between the i -th and $(i+1)$ st surfaces. Incidentally, the stop and the final image plane, too, are shown each as one plane.

15 The embodiments of the invention have spherical surfaces and aspheric surfaces of revolution asymmetry. Of these, the spherical ones are taken as sphere and described by the radii of curvature R_i with plus sign when the center of curvature falls on the plus side of the z axis of the local coordinates, or minus sign when it falls on the minus side.

Here, the shape of the spherical surface is expressed by the following equation:

ENTRANCE PUPIL

20

$$z = \frac{(x^2 + y^2)/R_i}{1 + \sqrt{1 - (x^2 + y^2)/R_i^2}}$$

(Y1 Y2 R1 R2)

The optical system of the invention includes at least one aspheric surface of revolution asymmetry, and its shape is expressed by the following equation:

25

$$\begin{aligned} z = & A/B + C_{02}y^2 + C_1xy + C_{20}x^2 + C_{03}y^3 + C_{12}xy^2 + C_{21}x^3y + C_{30}x^5 \\ & + C_{04}y^4 + C_{13}xy^3 + C_{22}x^2y^2 + C_{31}x^3y + C_{40}x^4y + C_{50}x^6 \\ & + C_{05}y^5 + C_{14}xy^4 + C_{23}x^2y^3 + C_{32}x^3y^2 + C_{41}x^4y + C_{51}x^5y + C_{60}x^6 \end{aligned}$$

where

35

$$A = (a+b)(y^2 \cdot \cos^2 t + x^2)$$

40

$$\begin{aligned} B = & 2a \cdot b \cdot \cos t [1 + \{(b-a) \cdot y \cdot \sin t / (2a \cdot b)\}] \\ & + [1 + \{(b-a) \cdot y \cdot \sin t / (a \cdot b)\}] \cdot (y^2 / (a \cdot b)) \\ & - \{4a \cdot b \cdot \cos^2 t + (a+b)^2 \cdot \sin^2 t \cdot x^2 / (4a^2 b^2 \cdot \cos^2 t)\}]^{1/2} \end{aligned}$$

45

In the surface formula described above, "A/B" shows the shape of the surface of the second order. So, this formula expresses the shape of the aspheric surface of revolution asymmetry based on the surface of the second order. In the 50 embodiments of the invention, however,

$$A/B = 0 \text{ is set.}$$

in the surface formula described above. This implies that the surface is of revolution asymmetry based on the plane. Specifically, regardless of the value of "t", the following condition is obtained:

$$a = b = \infty$$

Further, all the surfaces of revolution asymmetry in the invention are formed to the shapes of plane symmetry with

respect to the yz -plane by using only the terms of even-numbered order in respect of "x" in the equation described above and putting "0" to the terms of odd-numbered order. Every surface of revolution asymmetry in the invention satisfies the following condition:

C₁₁=C₁₂=G₃₀=C₁₃=C₃₁=C₁₄=C₃₂=C₅₀=C₁₅=C₃₃=C₅₁=0

The term "horizontal semifield u_y " means a half of the maximum angular field the system covers at the first surface R1 in the YZ plane in Fig. 5. The term "vertical semifield u_x " means a half of the maximum angular field the system covers at the first surface R1 in the XZ plane.

Also, the diameter of the stop is shown as the aperture diameter. This regulates the brightness of the optical system. Also, the effective area of the image plane is shown as the image size. The image area is of the rectangular shape with the horizontal sides in the y direction of the local coordinates, and the vertical sides in the x direction.

Also, for the numerical example of each of the embodiments, its lateral aberrations are graphically represented in the wide-angle end (W), the middle position (M) and the telephoto end (T), as rays of light are incident on the stop R1 at respective horizontal and vertical angles of: (u_y, u_x) , $(0, u_x)$, $(-u_y, u_x)$, $(u_y, 0)$, $(0, 0)$ and $(-u_y, 0)$. In the graphs of the lateral aberrations, the abscissa is in the height of incidence on the pupil and the ordinate is in the produced amount of aberration. In any of the embodiments, every surface is basically formed to symmetric shapes with respect to the yz plane. Even in the graphs of the lateral aberrations, therefore, the plus and minus directions of the vertical angular field become the same. So, the graphs of the lateral aberrations of the minus direction are omitted for the purpose of simplifying the drawings.

Numerical examples of embodiments 6 to 8 are shown below.

(Embodiment 6) The center of a top view of a topographic map, as shown below, is the center of a topographic map, as shown below.

This numerical example of the embodiment 6 provides a zoom optical system whose range is about 1:9. Figs. 34, 35 and 36 are sectional views of the zoom optical system with the optical paths shown in the wide-angle end (W), the middle position (M) and the telephoto end (T), respectively. The point α is an intersection point of the entering reference axis and each surface defined by a direction of the entering reference axis and a direction of the exiting reference axis. An object point β is the intersection point between the optical axis and an object with a distance d_{obj} from the reference axis, and the exiting reference axes, respectively. The zoom optical system consists of an objective lens, a zooming reference axis, a diaphragm, a first optical element, a second optical element, a third optical element and a coaxial optical element. In order from an object side along the optical axis, the first optical element is a negative meniscus-shaped lens, the second optical element is a positive meniscus-shaped lens, the third optical element is a biconvex lens, and the coaxial optical element has the coaxial optical axis.

	W	M	T
Horizontal Semifield	27.2	21.6	14.4
Vertical Semifield	18.9	14.6	9.7
Aperture Diameter	8.00	8.00	8.00

two off-axial reflecting surfaces integrally formed by a front lens element having two refracting surfaces and

The Committee of the Central Executive will, after the adoption of the existing resolution, draw up each of the three so-called General Comptrollership documents and submit them to open debate.

The first of several 'walked' meetings, the group had the support of various local organisations. See it through to the end.

The central optical element, the second off-axis mirror, generates over the central optical element range, depending on each other, the following:

The direction of the existing reference axis and the direction of the exiting reference axis of each pair of adjacent off-axis optical elements cross the geometrical path of each other; and the first off-axis optical element, the stop and the second off-axis optical element, the lens.

The coaxial signal standard is a sympathetic lens.

Fig. 290 shows diagram of the optical design of one embodiment of this type of optical system according to the invention. A reference wave ray 12 passes at the center of the aperture opening of a stop 13 and arrives at the center of a final image plane 14. Optical elements 15 and 16 each have a magnifying surface (not shown) applied to the reference wave ray 12. The inclined reflecting surface to the entering reference wave is hereinafter called the "tilted" reflecting surface 15; the flat reflecting surface applied to the reference wave ray 12 is hereinafter called the "flat" reflecting surface 16. The last off-axial optical element 17 and the converging lens element 18 are converging along the converging axis 19 to the left in this view from the object side.

A third optical element located along symmetry axis, conjugate to the one before it by 10 mm, consists of a lens 16 (or similar optical element) + dispensed before the flat wedge plane 18. Placed off-axis optical element 16, the stop 17 and the second off-axis optical element 14 in accordance with FIG. 2, can produce a strong focusing zooming. The three optical elements 14, 16 and 17 may be moved over the range required.

After all, it's hard to find a positive example of a Ma Eng; the ones I can think of find a negative example more often than not, they consistently represent strong feelings, a unwillingness to power, an unwillingness to restrain the people, and a desire

EP 0 790 513 A2

i	Yi	Zi(W)	θi	D _i	N _{di}	v _{di}	Sur.
First Optical Element B1:							
1	0.00	0.00	0.00	16.00	1.51741	52.41	R
2	0.00	16.00	30.00	20.00	1.51741	52.41	L
3	-17.32	6.00	30.00	16.00	1.51741	52.41	L
4	-17.32	22.00	0.00	2.00	1		R
5	-17.32	24.00	0.00	2.00	1		Stop
Second Optical Element B2:							
6	-17.32	26.00	0.00	8.00	1.51741	52.41	R
7	-17.32	40.00	-30.00	20.00	1.51741	52.41	L
8	0.00	30.00	-30.00	16.00	1.51741	52.41	L
9	0.00	46.00	0.00	Var.	1		R
Third Optical Element B3:							
10	0.00	62.38	0.00	2.80	1.83480	42.72	R
11	0.00	65.18	0.00	Var.	1		R
12	0.00	84.40	0.00		1		I.P.

	I ₂ W	M _i	T
D9	16.38	11.60	5.58
D11	19.22	33.77	69.22

R 1 + up to R 9: Zi(M) = Zi(W) - 9.76

Zi(T) ≠ Zi(W) - 39.20

R10 + up to R11: Zi(M) = Zi(W) - 14.55

Zi(T) = Zi(W) - 50.00

R12:

Zi(M) = Zi(W)

Zi(T) ≠ Zi(W)

Shape of Spherical Surface:

R 1 Surface: R₁ = -70.000

R 4 Surface: R₄ = ∞

R 6 Surface: R₆ = ∞

R 9 Surface: R₉ = -30.024

R10 Surface: R₁₀ = -34.943

R11 Surface: R₁₁ = 262.245

Shape of Aspheric Surface:

R 2: C₀₂ = 1.17370e-02 C₂₀ = 6.60704e-03

C₀₃ = -8.20960e-05

C₀₄ = 4.42532e-06

C₂₁ = 3.17239e-05

C₂₂ = 1.70696e-05

C₄₀ = 8.12432e-06

$C_{05}=-1.95325e-07$, $C_{23}=4.57659e-07$, $C_{41}=5.28528e-08$, $C_{06}=1.43266e-08$, $C_{24}=5.50930e-08$, $C_{42}=6.05424e-08$, $C_{60}=2.85711e-08$

5 R 3: $C_{02}=4.78752e-03$, $C_{20}=6.08577e-03$
 $C_{03}=8.04000e-06$, $C_{21}=-2.48947e-05$, $C_{22}=5.58110e-06$, $C_{40}=3.62312e-06$
 $C_{04}=-8.47604e-08$, $C_{23}=-8.90555e-08$, $C_{41}=-1.93993e-08$, $C_{05}=3.57983e-09$, $C_{24}=2.72588e-09$, $C_{42}=1.86232e-09$, $C_{60}=5.94017e-09$

10 R 7: $C_{02}=-6.10763e-03$, $C_{20}=6.78303e-04$, the refractive index may take number of the medium between the
 $C_{03}=2.10107e-05$, $C_{21}=-2.95023e-05$, the thin lens plane, the optical path length, $C_{22}=5.68199e-06$, $C_{40}=8.04608e-06$,
 $C_{04}=4.32906e-07$, $C_{23}=-1.01568e-07$, $C_{41}=-1.36560e-07$, the distance from the plane, which is the
 $C_{05}=6.44143e-09$, $C_{24}=2.17578e-09$, $C_{42}=-4.18606e-09$, the optical path length, $C_{60}=-7.66468e-09$

15 R 8: $C_{02}=-8.05505e-03$, $C_{20}=2.18969e-03$
 $C_{03}=-2.78436e-05$, $C_{21}=-1.86649e-05$, $C_{22}=6.81965e-06$, $C_{40}=3.17321e-06$
 $C_{04}=-3.36701e-06$, $C_{23}=-1.17535e-08$, $C_{41}=1.52834e-08$
 $C_{05}=2.21811e-08$, $C_{24}=1.70935e-09$, $C_{42}=-1.57102e-08$, face to combination lens unit, and its shape
 $C_{60}=8.28707e-09$, along a direction.

25 The constituent parts of the present embodiment are described in the order from the object side. A first optical element B1 is constructed with a first surface R1 (refracting entrance surface of concave form), a second surface R3 and a third surface R5 which are in curved form of inner reflection and decentered, and a fourth surface R4 (refracting exit surface of plain form) in one transparent body. The second surface R2 acts as a convex reflecting surface. A fifth surface R5 is a stop plane. A second optical element B2 is constructed with a sixth surface R6 (refracting entrance surface of plain form), a seventh surface R7 and an eighth surface R8 which are in curved form of inner reflection and decentered, and a ninth surface R9 (refracting exit surface of convex form) in one transparent body. The eighth surface R8 acts as a convex reflecting surface. A third optical element B3 is in the form of a negative lens with a tenth surface R10 and an eleventh surface R11 coaxial to each other. A twelfth surface R12 is the final image plane coincident with the image receiving surface of an image pickup device such as a CCD.

The first optical element B1, the stop R5 and the second optical element B2 have a positive overall refractive power and move in unison, constituting a first lens unit (front lens unit). The third optical element B3 has a negative refractive power, constituting a second lens unit (rear lens unit) which moves during zooming.

Next, the image forming function is described on the assumption that an object is at infinity. A light beam coming from an object first enters the first optical element B1, and the light beam is refracted in passing through the first surface R1, then reflected from the second surface R2 and the third surface R3 successively, and then refracted in exiting from the fourth surface R4.

The light beam, after having passed through the stop or the fifth surface R5, then enters the second optical element B2, where the light beam is refracted at the sixth surface R6, then reflected from the seventh surface R7 and the eighth surface R8 successively, and then refracted at the ninth surface R9, exiting from the second optical element B2.

The light beam then enters the third optical element B3, where the light beam is refracted at the tenth surface R10 and the eleventh surface R11 and exits from the third optical element B3.

The light beam that has exited from the third optical element B3 finally forms an image on the twelfth surface R12. Each of the first and second off-axial optical elements B1 and B2 of the present embodiment is an off-axial optical element in which the entering reference axis and the exiting reference axis are oriented to the same direction.

Next, the function of varying the image magnification by moving the lens units is described. The present embodiment is a 2-unit zoom lens of plus-minus power arrangement in this order from the object side. During zooming from the wide-angle end to the telephoto end, the front lens unit and the rear lens unit both move to the minus direction in the Z axis, while narrowing the separation therebetween. In this case, the stop R5 is of variable thickness depending on the plane.

55 Figs. 37, 38 and 39 are graphs of the lateral aberrations of such an optical system in the wide-angle end (W), a middle position (M) and the telephoto end (T). These graphs are depicted with regard to six rays of light which enter the optical system at angles of (u_y, u_x) , $(0, u_x)$, $(-u_y, u_x)$, $(u_y, 0)$, $(0, 0)$ and $(-u_y, 0)$ with the Y axis and the X axis. Incidentally, the abscissa of each graph is in the height of incidence of the entering ray on the stop R5 in the Y and X directions.

As can be seen from the graphs, the aberrations are corrected in good balance in each of the zooming positions.

Incidentally, it is premised in the present embodiment that the image size is 36 mm x 24 mm.

(Embodiment 7)

FIG. 42

5 The numerical example of the embodiment 7 provides a zoom optical system whose range is about 1.9. Figs. 40,
41 and 42 are sectional views of the zoom optical system with the optical paths shown in the wide-angle end (W), a
middle position (M) and the telephoto end (T), respectively.

10	DIRECTION	A	EXPLANATION			
			W	M	T	
15			Horizontal Semifield	27.2	21.6	14.4
			Vertical Semifield	18.9	14.6	9.7
			Aperture Diameter	8.00	8.00	8.00

20	i	Yi	Zi(W)	θi	Di	Ndi	vdi	Sur.	
First Optical Element B1:									
25	1	0.00	0.00	0.00	16.00	1.51741	52.41	R	
	2	0.00	16.00	28.00	17.00	1.51741	52.41	L	
	3	-14.09	6.49	73.00	24.00	1.51741	52.41	L	
	4	9.91	6.49	90.00	2.00	1	1	R	
	5	11.91	6.49	90.00	2.00	1	1	Stop	
30	Second Optical Element B2:								
	6	13.91	6.49	90.00	16.00	1.51741	52.41	R	
	7	35.91	6.49	70.00	17.00	1.51741	52.41	L	
	8	22.88	-4.43	25.00	20.00	1.51741	52.41	L	
	9	22.88	15.57	0.00	Var.	1	1	R	
35	Third Optical Element B3 (Negative Lens):								
40	10	22.88	31.99	0.00	2.80	1.83480	42.72	R	
	11	22.88	34.79	0.00	Var.	1	1	R	
	12	22.88	55.07	0.00		1	1	I.P.	

	W	M	T	
50	D 9	16.43	11.93	6.30
	D11	20.28	34.79	70.28

55 R 1 + up to R 9: $Zi(M) = Zi(W) - 10.01$
 $Zi(T) = Zi(W) - 39.88$

R10 + up to R11: $Zi(M) = Zi(W) - 14.51$
 $Zi(T) = Zi(W) - 50.00$

TELEPHOTO END

R12: $Z_i(M) = Z_i(W)$
 $Z_i(T) = Z_i(W)$

Shape of Spherical Surface:

	R 1 Surface: $R_1 = -60.000$	R 4 Surface: $R_4 = \infty$	R 6 Surface: $R_6 = \infty$	R 9 Surface: $R_9 = -35.226$	R10 Surface: $R_{10} = -42.989$	R11 Surface: $R_{11} = 94.318$
5						
10						
15						
20						

Shape of Aspheric Surface:

15	R 2: $C_{02}=1.79244e-02$	$C_{20}=-1.52002e-04$	$C_{03}=2.91478e-04$	$C_{21}=-4.53461e-05$	$C_{04}=-6.15025e-06$	$C_{22}=-2.99463e-06$	$C_{05}=1.04508e-06$	$C_{23}=1.86002e-07$	$C_{06}=7.13288e-08$	$C_{24}=8.65582e-09$	$C_{07}=6.59757e-09$	C_{25}
20												
25	R 3: $C_{02}=6.97073e-03$	$C_{20}=-9.56998e-04$	$C_{03}=6.11813e-05$	$C_{21}=-4.53546e-05$	$C_{04}=-4.08851e-06$	$C_{22}=-1.86658e-06$	$C_{05}=3.03036e-07$	$C_{23}=6.29105e-08$	$C_{06}=-1.24765e-08$	$C_{24}=-3.65030e-09$	$C_{07}=1.64066e-08$	C_{25}
30	R 7: $C_{02}=-8.55985e-03$	$C_{20}=-2.21093e-03$	$C_{03}=1.12454e-05$	$C_{21}=-3.52367e-05$	$C_{04}=-2.60229e-07$	$C_{22}=-1.96530e-06$	$C_{05}=-1.79083e-09$	$C_{23}=-4.59509e-08$	$C_{06}=-1.47512e-09$	$C_{24}=-3.24982e-09$	$C_{07}=-1.94830e-09$	C_{25}
35	R 8: $C_{02}=-1.36422e-02$	$C_{20}=1.92964e-03$	$C_{03}=2.54697e-04$	$C_{21}=-6.64828e-05$	$C_{04}=-9.76231e-06$	$C_{22}=-3.77447e-06$	$C_{05}=-4.48426e-07$	$C_{23}=-1.79772e-07$	$C_{06}=-4.46303e-09$	$C_{24}=9.64066e-09$	$C_{07}=-3.30943e-09$	C_{25}
40												
45												
50												
55												

$$Z(T) = Z(W) = 30.60$$

The constituent parts of the present embodiment are described successively in the order from the object side. A first optical element B1 is constructed with a first surface R1 (refracting entrance surface of concave form), a second

surface R3 and a third surface R3 which are in curved form of inner reflection and decentered, and a fourth surface R4 (refracting exit surface of plain form) in one transparent body. The second surface R2 acts as a convex reflecting surface. A fifth surface R5 is a stop plane. A second optical element B2 is constructed with a sixth surface R6 (refracting entrance surface of plain form); a seventh surface R7 and an eighth surface R8 which are in curved form of inner reflection and decentered; and a ninth surface R9 (refracting exit surface of convex form) in one transparent body. The eighth surface R8 acts as a convex reflecting surface. A third optical element B3 is in the form of a negative lens with a tenth surface R10 and an eleventh surface R11 coaxial to each other. A twelfth surface R12 is the final image plane coincident with the image receiving surface of an image pickup device such as a CCD.

The first optical element B1, the stop R5 and the second optical element B2 have a positive overall refractive power and move in unison, constituting a first lens unit (front lens unit). The third optical element B3 has a negative refractive power, constituting a second lens unit (rear lens unit) which moves during zooming.

Next, the image forming function is described on the assumption that an object is at infinity. A light beam coming from an object first enters the first optical element B1; and the light beam is refracted in passing through the first surface R1, then is reflected from the second surface R2 and the third surface R3 successively, and then is refracted at the fourth surface R4, exiting from the first optical element B1.

The light beam, after having passed through the stop or the fifth surface R5, then enters the second optical element B2, where the light beam is refracted at the sixth surface R6, then is reflected from the seventh surface R7 and the eighth surface R8 successively, and then is refracted at the ninth surface R9, exiting from the second optical element B2.

5 The light beam then enters the third optical element B3, where the light beam is refracted at the tenth surface R10 and the eleventh surface R11 and exits from the third optical element B3.

The light beam that has exited from the third optical element B3 finally forms an image on the twelfth surface R12.

Each of the first and second optical elements B1 and B2 of the present embodiment is an off-axial optical element in which the entering reference axis and the exiting reference axis are orthogonal to each other.

10 Next, the function of varying the image magnification by moving the lens units is described. The present embodiment is a 2-unit zoom lens of plus-minus power arrangement in this order from the object side. During zooming from the wide-angle end to the telephoto end, the front lens unit and the rear lens unit both move to the minus direction in the Z axis, while narrowing the separation therebetween.

15 Figs. 43, 44 and 45 are graphs of the lateral aberrations of such an optical system in the wide-angle end (W), the middle position (M) and the telephoto end (T), respectively. These aberrations are produced by six rays of light which enter the optical system at angles of (u_y, u_x) , $(0, u_x)$, $(-u_y, u_x)$, $(u_y, 0)$, $(0, 0)$ and $(-u_y, 0)$ with the Y axis and the X axis. Incidentally, the abscissa of each graph is in the height of incidence of the entering ray on the stop R5 in the Y and X directions.

As can be seen from the graphs, the aberrations are corrected in good balance in each of the zooming positions.

20 It is premised in the present embodiment that the image size is 36 mm x 24 mm.

(Embodiment 8)

25 A numerical example of the embodiment 8 provides a zoom optical system whose range is about 1.9. Figs. 46, 47 and 48 are sectional views of the zoom optical system with the optical paths shown in the wide-angle end (W), a middle position (M) and the telephoto end (T), respectively.

30

MIDDLE POSITION

	W	M	T
Horizontal Semifield	27.2	21.6	14.4
Vertical Semifield	18.9	14.6	9.7
Aperture Diameter	8.00	8.00	8.00

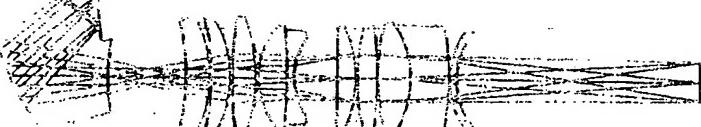
35



40



45



50

TELEPHOTO END

55

i	Yi	Zi(W)	θi	Di	Ndi	vdi	Sur.
First Optical Element B1:							
1	0.00	0.00	0.00	16.00	1.51741	52.41	R
2	0.00	16.00	30.00	20.00	1.51741	52.41	L
3	-17.32	6.00	30.00	16.00	1.51741	52.41	L
4	-17.32	22.00	0.00	Var.	1		R
5	-17.32	24.00	0.00	2.00	1		Stop
Second Optical Element B2:							
6	-17.32	26.00	0.00	8.00	1.51741	52.41	R
7	-17.32	40.00	-30.00	20.00	1.51741	52.41	L
8	0.00	30.00	-30.00	16.00	1.51741	52.41	L
9	0.00	46.00	0.00	Var.	1		R
Third Optical Element B3 (Negative Lens):							
10	0.00	62.06	0.00	2.80	1.83480	42.72	R
11	0.00	64.86	0.00	Var.	1		R
12	0.00	84.15	0.00		1		I.P.

	W	M	T
D 4	2.00	3.58	2.17
D 9	16.06	11.16	5.20
D11	19.29	34.31	69.29

- 40 R 1 + up to R 4: $Zi(M) = Zi(W) - 11.70$
 $Zi(T) = Zi(W) - 39.31$
- R 5 + up to R 9: $Zi(M) = Zi(W) - 10.12$
 $Zi(T) = Zi(W) - 39.14$
- R10 + up to R11: $Zi(M) = Zi(W) - 15.02$
 $Zi(T) = Zi(W) - 50.00$
- R12: $Zi(M) = Zi(W)$
 $Zi(T) = Zi(W)$

Shape of Spherical Surface:

- 50 R 1 Surface: $R_1 = -70.000$
R 4 Surface: $R_4 = -1095.034$
R 6 Surface: $R_6 = 1694.773$
R 9 Surface: $R_9 = -30.368$
55 R10 Surface: $R_{10} = -39.973$
R11 Surface: $R_{11} = 142.109$

ANGLE-END

Shape of Aspheric Surface:

R 2:	$C_{02}=1.14912e-02$	$C_{20}=6.26525e-03$	$C_{21}=8.20929e-05$	$C_{22}=1.01293e-05$	$C_{40}=8.27507e-06$	$C_{41}=1.26644e-07$	$C_{42}=4.61438e-08$
5	$C_{03}=-4.77249e-05$	$C_{23}=-7.02287e-08$	$C_{24}=3.35166e-08$				
	$C_{04}=4.10346e-06$						
	$C_{05}=-1.63961e-07$						
	$C_{06}=2.44243e-08$						
	$C_{60}=1.61883e-08$						
10	R 3:	$C_{02}=4.89298e-03$	$C_{20}=5.68104e-03$	$C_{21}=1.25831e-05$	$C_{22}=3.13563e-06$	$C_{40}=3.87963e-06$	$C_{41}=-2.44966e-08$
		$C_{03}=1.68581e-05$		$C_{23}=-2.17112e-08$		$C_{42}=1.62318e-09$	
	$C_{04}=-2.55210e-08$						
	$C_{05}=4.20901e-09$						
	$C_{06}=8.49458e-10$						
15		$C_{60}=4.20862e-10$					
	R 7:	$C_{02}=-5.69972e-03$	$C_{20}=3.42455e-04$	$C_{21}=1.29391e-05$	$C_{22}=2.91471e-06$	$C_{40}=7.06278e-06$	$C_{41}=-8.96749e-08$
20		$C_{03}=-1.25357e-05$		$C_{23}=-5.06508e-08$		$C_{42}=-6.12969e-09$	
	$C_{04}=-3.47554e-07$						
	$C_{05}=6.35559e-10$						
	$C_{06}=-7.42470e-10$						
	$C_{60}=-2.91694e-09$						
25	R 8:	$C_{02}=-7.33488e-03$	$C_{20}=2.03905e-03$	$C_{21}=1.50942e-05$	$C_{22}=2.76445e-06$	$C_{40}=-2.81122e-06$	$C_{41}=-3.98591e-09$
		$C_{03}=-9.78920e-07$		$C_{23}=-6.48211e-09$		$C_{42}=-1.14923e-08$	
	$C_{04}=-2.79340e-06$						
	$C_{05}=5.73943e-08$						
	$C_{06}=-6.05073e-09$						
	$C_{60}=-6.63843e-09$						

The constituent parts of the present embodiment are described successively in the order from the object side. A first optical element B1 is constructed with a first surface R1 (refracting entrance surface of concave form), a second surface R3 and a third surface R3 which are in curved form of inner reflection and decentered, and a fourth surface R4 (refracting exit surface of almost plain form) in one transparent body. The second surface R2 acts as a convex reflecting surface. A fifth surface R5 is a stop plane. A second optical element B2 is constructed with a sixth surface R6 (refracting entrance surface of almost plain form), a seventh surface R7 and an eighth surface R8 which are in curved form of inner reflection and decentered, and a ninth surface R9 (refracting exit surface of convex form) in one transparent body. The eighth surface R8 acts as a convex reflecting surface. A third optical element B3 is in the form of a negative lens with a tenth surface R10 and an eleventh surface R11 coaxial to each other. A twelfth surface R12 is the final image plane coincident with the image receiving surface of an image pickup device such as a CCD.

The first optical element B1 constitutes a first lens unit. The stop R5 and the second optical element B2 constitute a second lens unit. The third optical element B3 constitutes a third lens unit.

Next, the image forming function is described on the assumption that an object is at infinity. A light beam coming from an object enters the first optical element B1, and the light beam is refracted at the first surface R1, then is reflected from the second surface R2 and the third surface R3 successively, and then is refracted at the fourth surface R4, exiting from the first optical element B1.

The light beam, after having passed through the stop or the fifth surface R5, then enters the second optical element B2, where the light beam is refracted at the sixth surface R6, then is reflected from the seventh surface R7 and the eighth surface R8 successively, and then is refracted at the ninth surface R9, exiting from the second optical element B2.

The light beam then enters the third optical element B3, where the light beam is refracted at the tenth surface R10 and the eleventh surface R11 and exits from the third optical element B3.

The light beam that has exited from the third optical element B3 finally forms an image on the twelfth surface R12.

Each of the first and second optical elements B1 and B2 of the present embodiment is an off-axial optical element in which the entering reference axis and the exiting reference axis are oriented to the same direction.

Next, the function of varying the image magnification by moving the lens units is described. The present embodiment is a 2-unit zoom lens of plus-minus power arrangement in this order from the object side. During zooming from the wide-angle end to the telephoto end, all of the lens units move to the minus direction in the Z axis. During this time, the separation between the first and second lens units once widens and then narrows, and the separation between the sec-

ond and third lens units narrows. It is noted in claim 1 that the image size is 36 mm x 24 mm, an image on the seventh surface.

Figs. 49, 50 and 51 are graphs of the lateral aberrations of such an optical system in the wide-angle end (W), the middle position (M) and the telephoto end (T), respectively. These aberrations are produced by six rays of light which enter the optical system at respective angles of (u_y, u_x) , $(0, u_x)$, $(-u_y, u_x)$, $(u_y, 0)$, $(0, 0)$ and $(-u_y, 0)$ with the Y axis and the X axis. The abscissa of each graph is in the height of incidence of the ray on the stop R5 in the Y and X directions.

As can be seen from the graphs, the aberrations are corrected in good balance in each of the zooming positions.

It is premised in the present embodiment that the image size is 36 mm x 24 mm, an image on the seventh surface.

The foregoing embodiments each have achieved a zoom optical system of which the total number of parts is reduced by using the off-axial optical element and the coaxial optical element that is formed only with the surfaces of rotation symmetry with respect to the ray of reference axis.

Another advantage of the invention arising from the fact that Zooming is performed by the off-axial optical element and the coaxial optical element that is formed only with the surfaces of rotation symmetry with respect to the ray of reference axis is that, despite the folding of the optical path to a desired shape in the interior of the optical system, all primary and decentering aberrations are corrected well throughout the entire zooming range. In such a manner, the zoom optical system of a smaller total number of parts and an image pickup apparatus using the same are achieved.

Another advantage arising from the use of the off-axial optical element having a number of reflecting surfaces given proper refractive power and arranged in decentered relation is that the optical path in the interior of the zoom optical system is folded to a desired polygon, thus shortening the total length of that zoom optical system in a certain direction.

Yet another advantage arising from the use of the off-axial optical element having formed in one transparent body

two refracting surfaces of proper refractive powers at the entrance and exit and a number of reflecting surfaces of proper refractive powers arranged in decentered relation from the reference axis, is that all primary aberrations and decentering aberrations are corrected well throughout the entire zooming range.

A furthermore advantage arising from the off-axial optical element having two refracting surfaces and a number of reflecting curved or plain surfaces formed in unison in one transparent body, is that the entirety of the zoom optical system is reduced to a minimum in bulk and size, while still permitting the problem of the severe positioning tolerance (setup tolerance) of the reflecting surfaces which has often held in the mirror system.

A zoom optical system comprises a plurality of optical elements. The plurality of optical elements include a first optical element having two refracting surfaces and a plurality of reflecting surfaces formed in a transparent body, being arranged such that a light beam enters an inside of the transparent body from one of the two refracting surfaces and, after being successively reflected from the plurality of reflecting surfaces, exits from the other of the two refracting surfaces, and/or a second optical element having a plurality of surface mirrors integrally formed and decentered relative to one another, being arranged such that an incident light beam exits therefrom after being successively reflected from reflecting surfaces of the plurality of surface mirrors, and a third optical element composed of a plurality of coaxial refracting surfaces. In the zoom optical system, an image of an object is formed through the plurality of optical elements, and zooming is effected by varying relative positions of at least two optical elements of the plurality of optical elements.

Claims

1. A zoom optical system comprising:

a plurality of optical elements including:

- a) a first optical element having two refracting surfaces and a plurality of reflecting surfaces formed in a transparent body, being arranged such that a light beam enters an inside of the transparent body from one of the two refracting surfaces and, after being successively reflected from the plurality of reflecting surfaces, exits from the other of the two refracting surfaces; and/or
- b) a second optical element having a plurality of surface mirrors integrally formed and decentered relative to one another, being arranged such that an incident light beam exits therefrom after being successively reflected from reflecting surfaces of the plurality of surface mirrors; and
- c) a third optical element composed of a plurality of coaxial refracting surfaces,

wherein an image of an object is formed through said plurality of optical elements, and zooming is effected by varying relative positions of at least two optical elements of said plurality of optical elements.

2. A zoom optical system according to claim 1, wherein a stop is disposed on a light entrance side of said zoom optical system, or adjacent to a light entrance surface at which a light beam first enters.

3. A zoom optical system according to claim 1 or 2, wherein each of said at least two optical elements of which relative positions are varied has an entering reference axis and an exiting reference axis in parallel to each other.

4. A zoom optical system according to claim 3, wherein said at least two optical elements of which relative positions are varied move in parallel to each other on one movement plane.
5. A zoom optical system according to claim 3, wherein each of said at least two optical elements of which relative positions are varied has an entering reference axis and an exiting reference axis oriented to the same direction.
6. A zoom optical system according to claim 3, wherein one of said at least two optical elements of which relative positions are varied has an entering reference axis and an exiting reference axis oriented to the same direction, and another of said at least two optical elements of which relative positions are varied has an entering reference axis and an exiting reference axis oriented to opposite directions.
7. A zoom optical system according to claim 3, wherein each of said at least two optical elements of which relative positions are varied has an entering reference axis and an exiting reference axis oriented to opposite directions.
8. A zoom optical system according to claim 1, wherein focusing is effected by moving one of said at least two optical elements of which relative positions are varied.
9. A zoom optical system according to claim 1, wherein focusing is effected by moving an optical element other than said at least two optical elements of which relative positions are varied.
10. A zoom optical system according to claim 1, wherein said zoom optical system forms at least once an object image at an intermediate point in an optical path thereof.
11. A zoom optical system according to claim 1, wherein curved reflecting surfaces among the plurality of reflecting surfaces are all formed to anamorphic shapes.
12. A zoom optical system according to claim 1, wherein all reference axes of said at least two optical elements of which relative positions are varied lie on one plane.
13. A zoom optical system according to claim 12, wherein at least a part of reference axes of an optical element other than said at least two optical elements of which relative positions are varied lie on said one plane.
14. A zoom optical system according to claim 1, wherein at least one optical element of said plurality of optical elements has a reflecting surface in which a normal line on the reflecting surface at an intersection point of a reference axis with the reflecting surface is inclined with respect to a movement plane on which said at least two optical elements of which relative positions are varied move.
15. An image pickup apparatus having a zoom-optical system according to claim 1, wherein the image of the object is formed on an image pickup plane of an image pickup medium.
16. A zoom optical system according to claim 1, further comprising a stop disposed between said plurality of optical elements.
17. A zoom optical system according to claim 1, wherein said third optical element is a single lens.
18. A zoom optical system according to claim 1, wherein said first optical element and said third optical element move during zooming.

WIDE-ANGLE END

Chromatographic structures

100-10200000
100-10200005
100-10200010
100-10200015
100-10200020
100-10200025

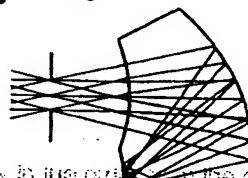
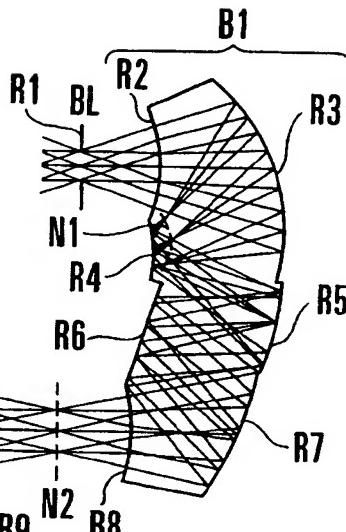
1. 1970-1972
2. 1973-1974
3. 1975-1976
4. 1977-1978
5. 1979-1980
6. 1980-1981
7. 1981-1982

The diagram shows a wire angle end component with several part numbers labeled: R27, R23, R19, R28, R24, R20, and P. The component has a central vertical slot and two angled ends. Part number R27 is at the top center, R23 is at the top right, R19 is at the top left, R28 is on the left side, R24 is on the right side, R20 is at the bottom right, and P is at the bottom center.

WIDE-ANGLE END

$\rho_{11} = -7.384489 \times 10^{-1}$
 $\rho_{12} = 1.789391 \times 10^{-1}$
 $\rho_{13} = 1.171340 \times 10^{-1}$
 $\rho_{14} = 5.78948 \times 10^{-1}$
 $\rho_{15} = -0.650768 \times 10^{-1}$
 $\rho_{16} = 0.130316 \times 10^{-1}$
R29
R26 **R25** **R22** **R21**
 $\rho_{21} = 1.04935 \times 10^{-1}$
 $\rho_{22} = 1.24448 \times 10^{-1}$
 $\rho_{23} = 4.82116 \times 10^{-1}$
 $\rho_{24} = 0.35571 \times 10^{-1}$

G. 1



The incident light path to the proposed embodiment is described successively in the following manner. A first optical element B1 is constructed with a first surface P1 (refracting entrance surface of lens) and a second surface P2 (stop plane). A third surface H3 which is in curved form of inner reflector, and an entrance surface P3 (reflecting exit surface of almost plain form) in one transpare of body. The second surface P2 is a curved reflecting surface. A fifth surface R6 is a stop plane. A second optical element B2 is constructed with a sixth surface R5 (refracting entrance surface of almost plain form) in one transpare of body, and an eighth surface R8 which is in curved form of inner reflector, and a ninth surface R9 (reflecting exit surface of almost plain form) in one transpare of body. The tenth surface R10 is as a negative lens with a depth surface H10 and an eleventh surface P11 which are coincident with each other. A twelfth surface H12 is the final image plane coincident with the image receiving surface of an image pickup device such as a CCD.

The first optical element B1 constitutes a first lens unit. The stop R5 and the second optical element B2 constitute a second lens unit. The third optical element B3 constitutes a third lens unit.

Next, the image forming function is described on the assumption that an object is at infinity. A light beam coming from an object enters the first optical element B1, and the light beam is refracted at the first surface R1, being reflected from the second surface R2 and the third surface R3 successively, and then is refracted again at the fourth surface R4, exiting from the fifth optical element B5.

The light beam, after having passed through the stop or the fifth surface 15, then it passes through the second optical element 16, where the light beam is reflected at the sixth surface 16a, then is reflected from the second optical element 16, and again successively, and thus it is reflected at the seventh surface 16b, exiting from the second optical element 16.

I have been able to see the first optical elements (Fig. 2) with the high vacuum system at the tenth surface (110) and the eleventh surface (111) and exits from the tube at the top of the telescope.

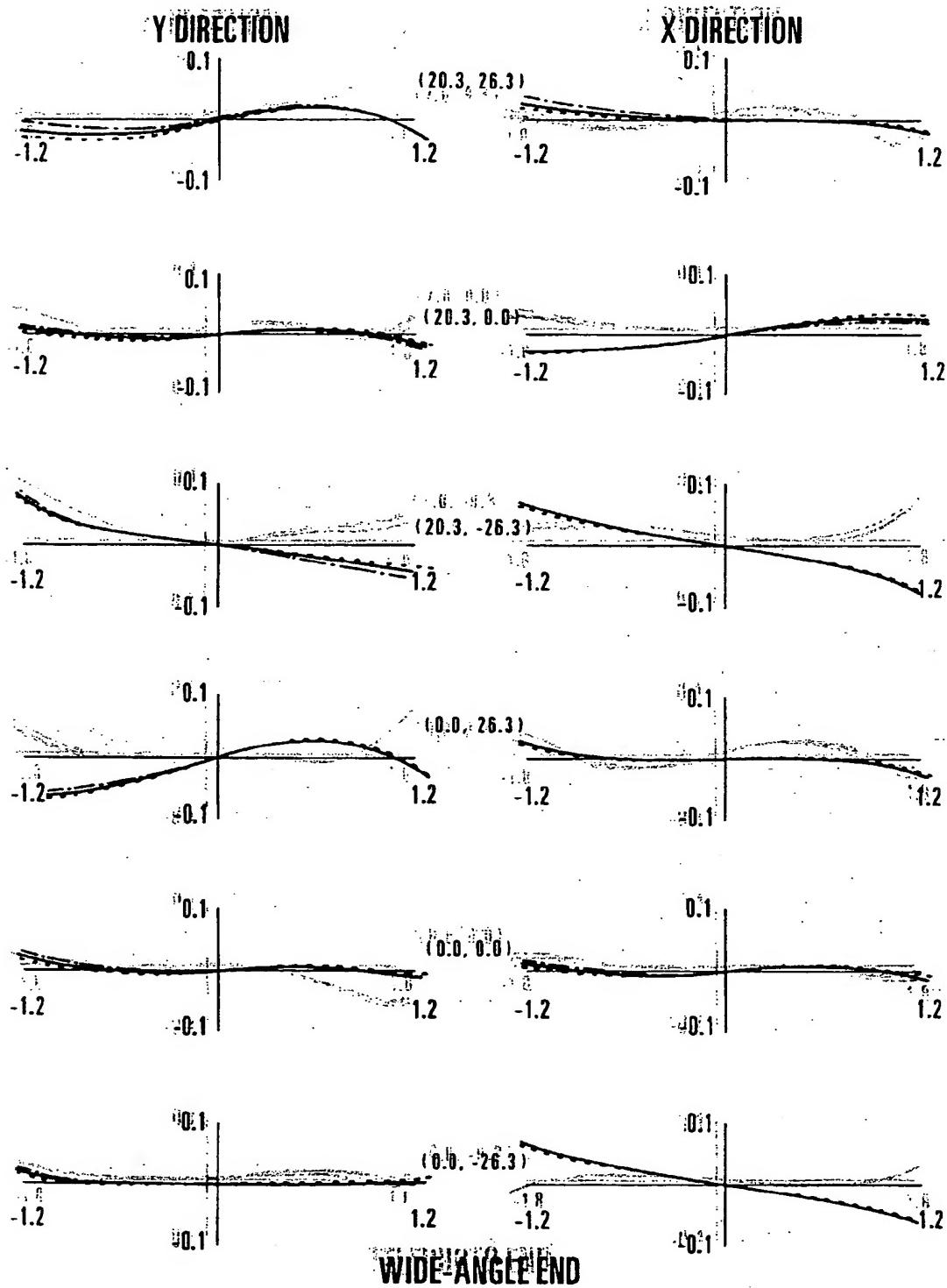
TELEPHOTO END (end serial)

in which the entering reference axis and the exit reference axis are parallel to each other.

Next, the function of varying the image magnification by moving the lenses units is described. The present embodiment is a 2-unit zoom lens of plus-minus power arrangement in this order from the object side. During zooming from the wide angle end to the telephoto end, all of the lens units move to the minus direction in the Z axis. During this time, the separation between the first and second lens units increases and then decreases, and the separation between the center

FIG. 12

(VERTICAL ANGLE OF VIEW, HORIZONTAL ANGLE OF VIEW)

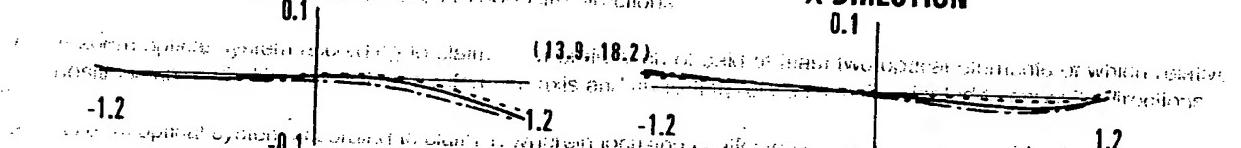


- Wetlands are the third largest carbon sink in the world, second only to oceans. However, wetlands are severely threatened by climate change and human activity, especially deforestation.*

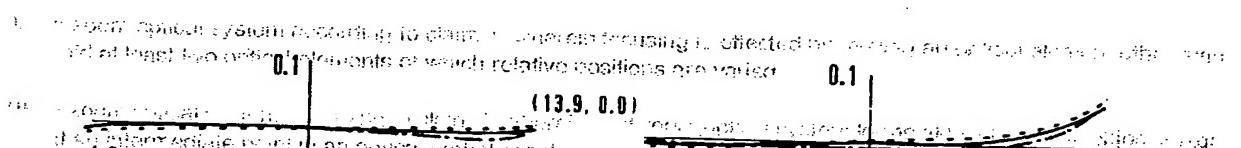
FIG. 3

- FIG. 3
Diagram of the different types of joints found in the brachiocephalic tracheobronchial system of various birds.

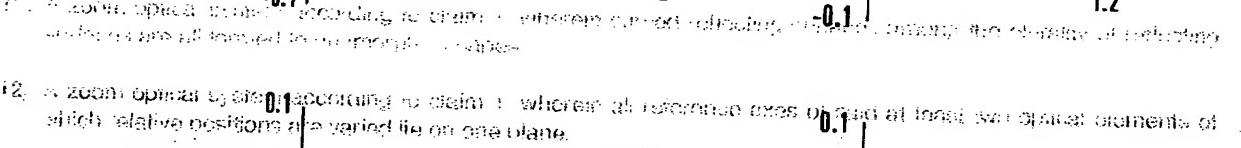
- (VERTICAL ANGLE OF VIEW, HORIZONTAL ANGLE OF VIEW)** the angles of which a bell or angle of view can be subtended by objects, structures and scenes, depending therefore upon the extent to the zenith, the horizon, and the direction of observation.



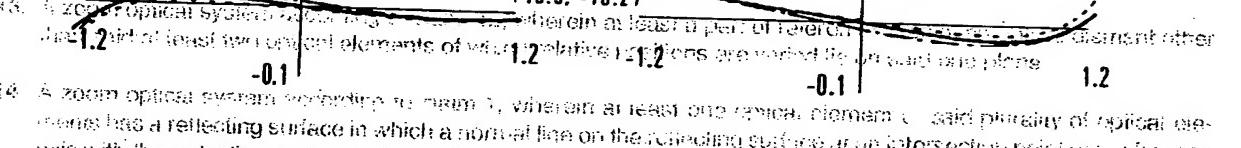
- The effects of initial condition on the final solution are tested.



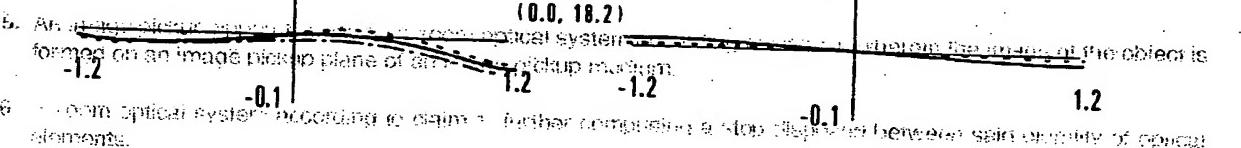
- 1.2 -0.1 1.2 -1.2 1.2



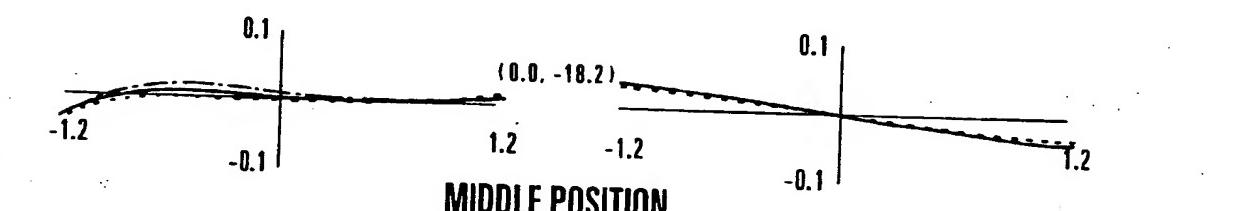
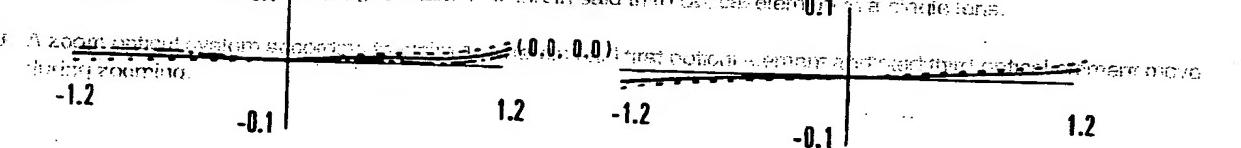
- (13.9, -18.2)



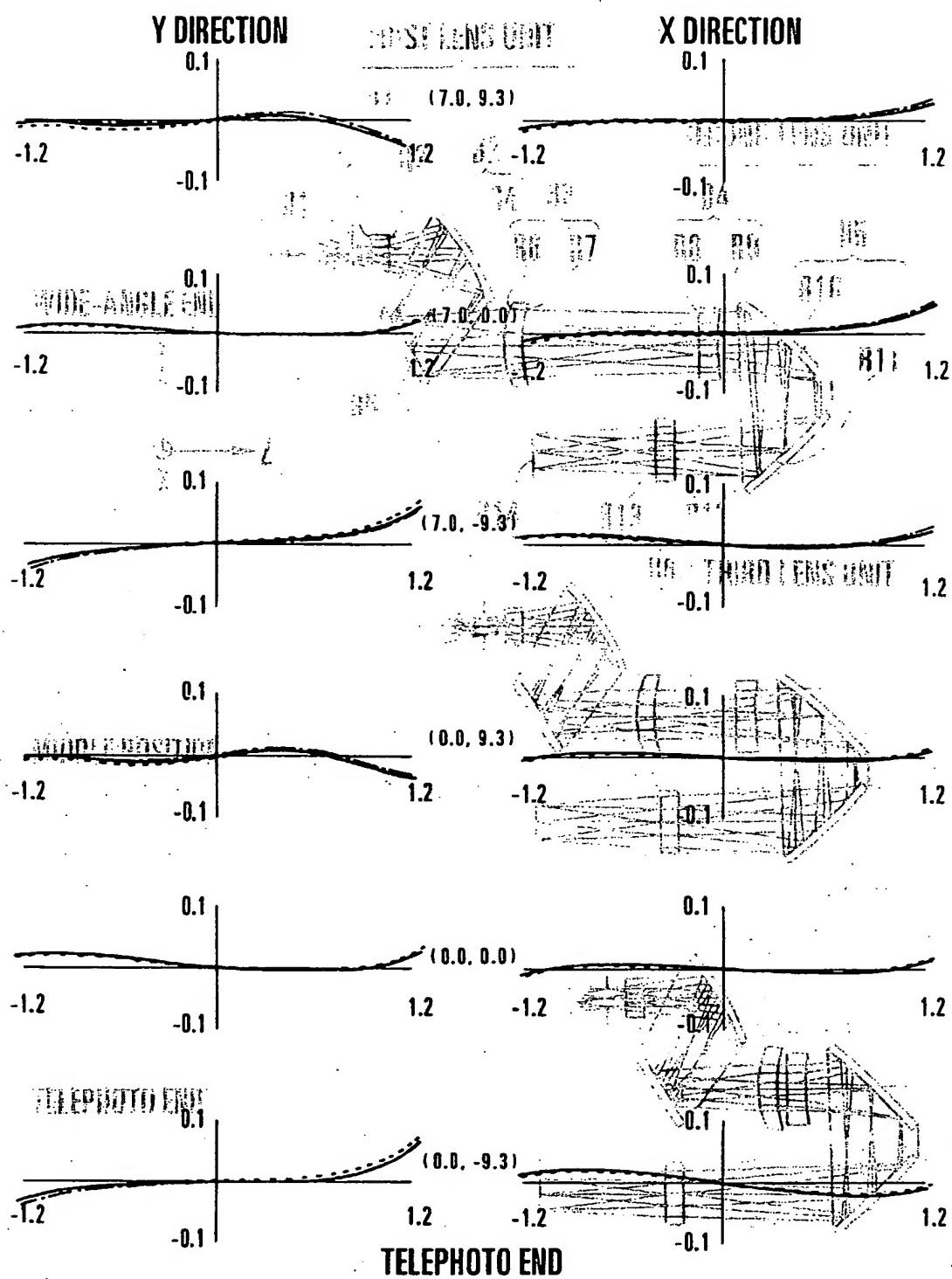
- axis with the reflecting surface is inclined with respect to a movement plane on which said at least two optical elements of which relative positions are varied move.



7. A zoom optical system **0.1** according to claim 1, wherein said third lens element **1** is a meniscus lens.



F I G. 4
 (VERTICAL ANGLE OF VIEW, HORIZONTAL ANGLE OF VIEW)



A 6 G 2

VERTICAL ANGLE OF VIEW, HORIZONTAL ANGLE OF VIEW

FIG. 5

CONVENTION

CONVENTION

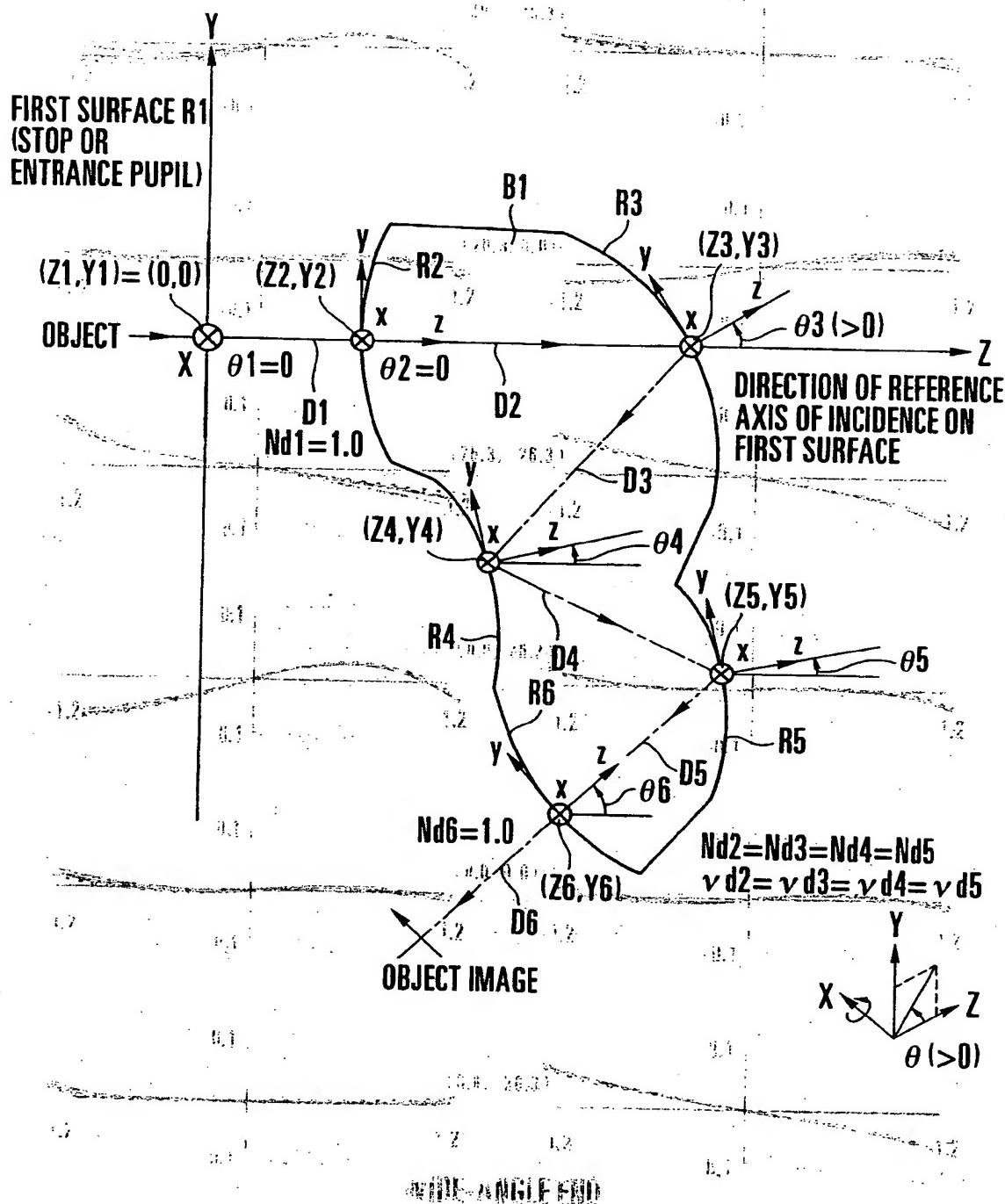


FIG. 6

ANFOCAL ANGLE OF VIEW, HORIZONTAL ANGLE OF VIEW

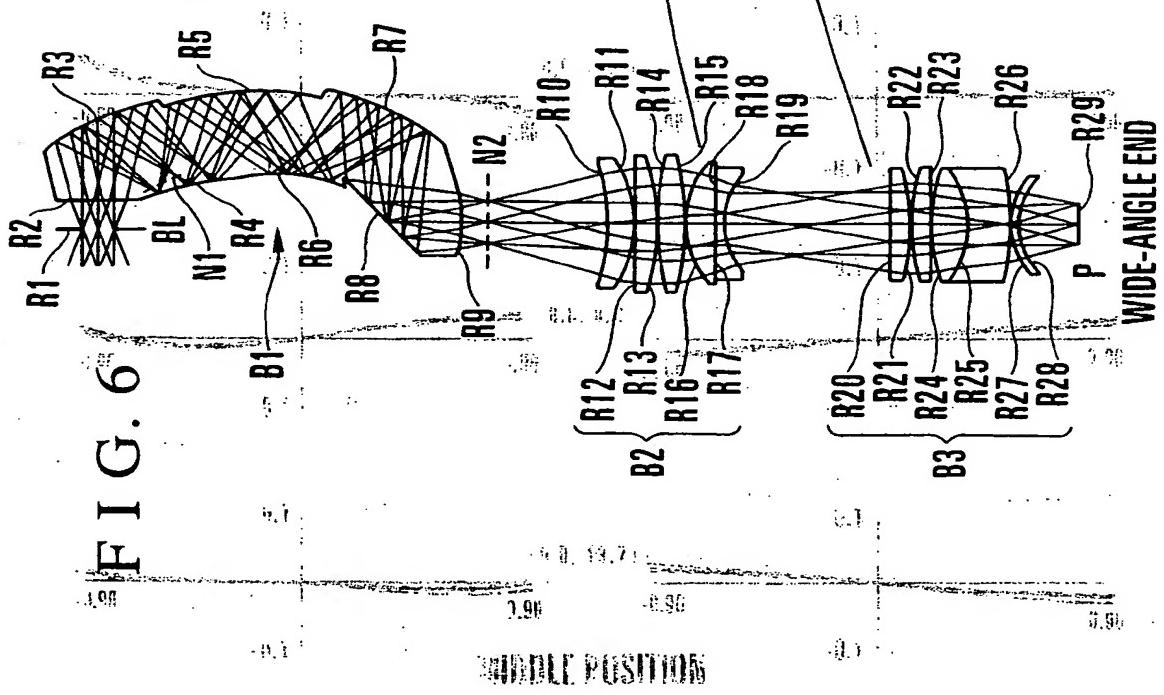
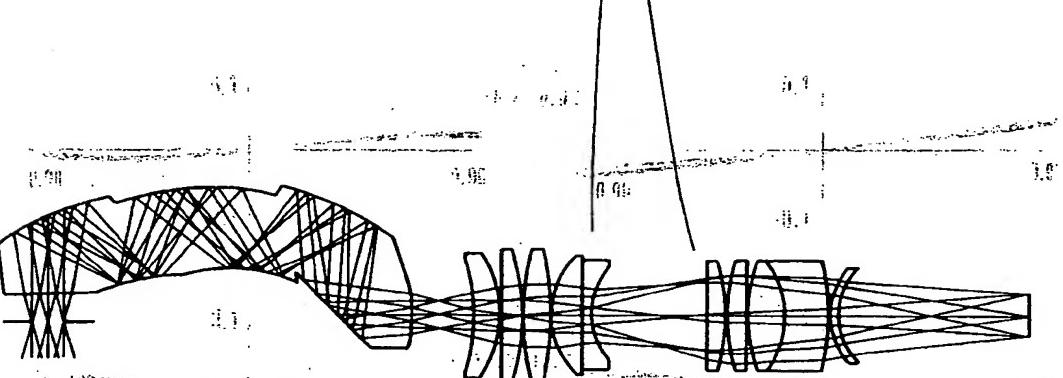
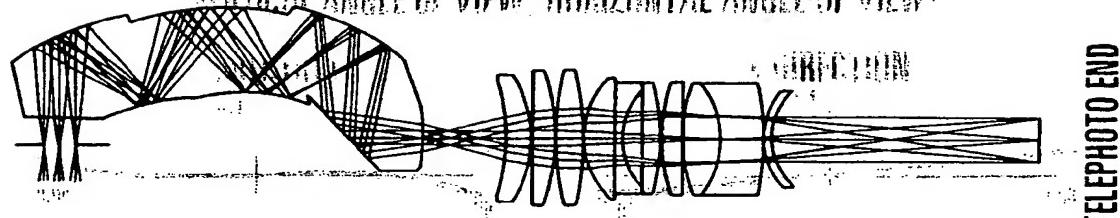
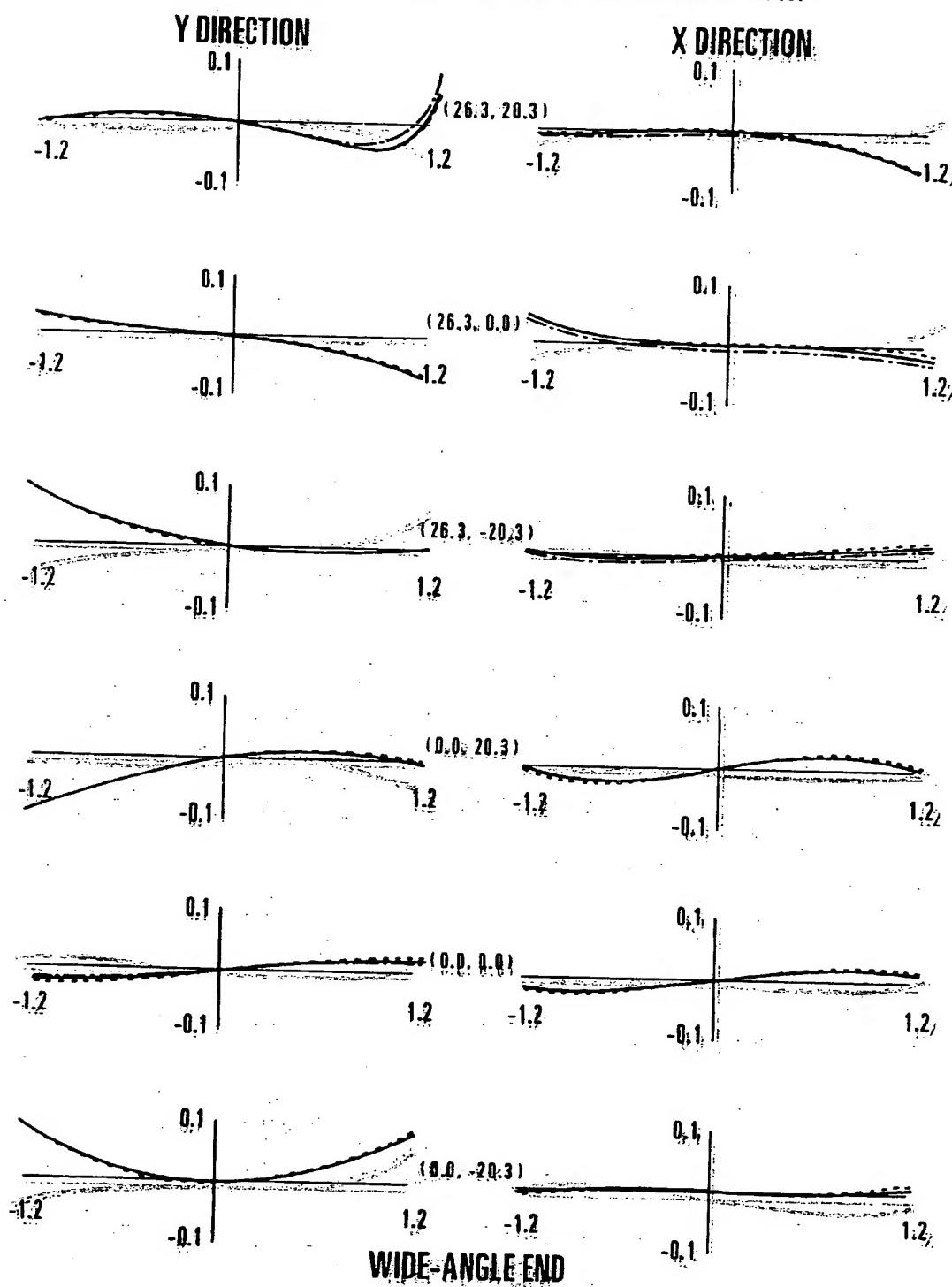


FIG. 7

(VERTICAL ANGLE OF VIEW, HORIZONTAL ANGLE OF VIEW)



F I G. 8

(VERTICAL ANGLE OF VIEW, HORIZONTAL ANGLE OF VIEW)

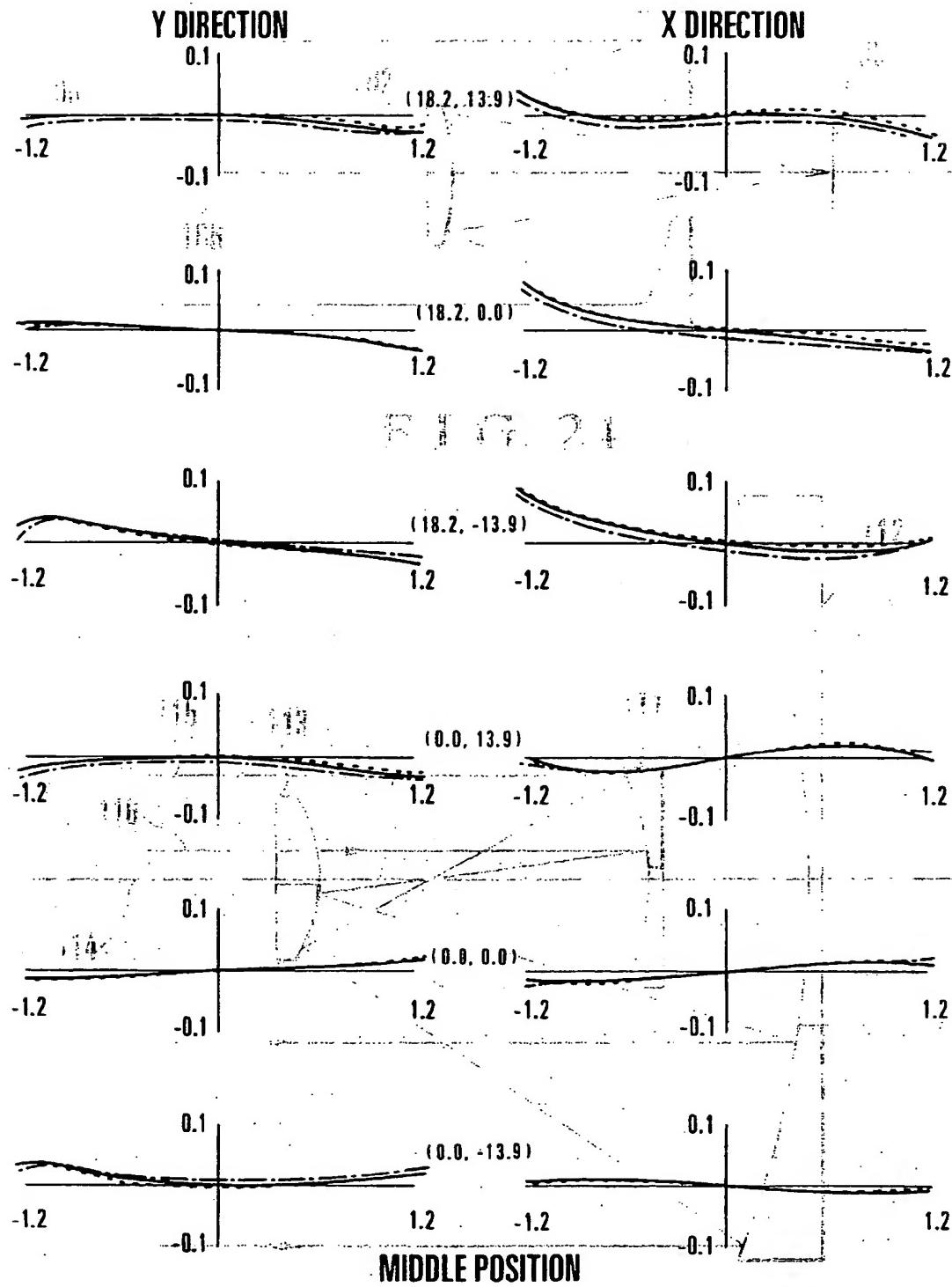


FIG. 9

(VERTICAL ANGLE OF VIEW, HORIZONTAL ANGLE OF VIEW)

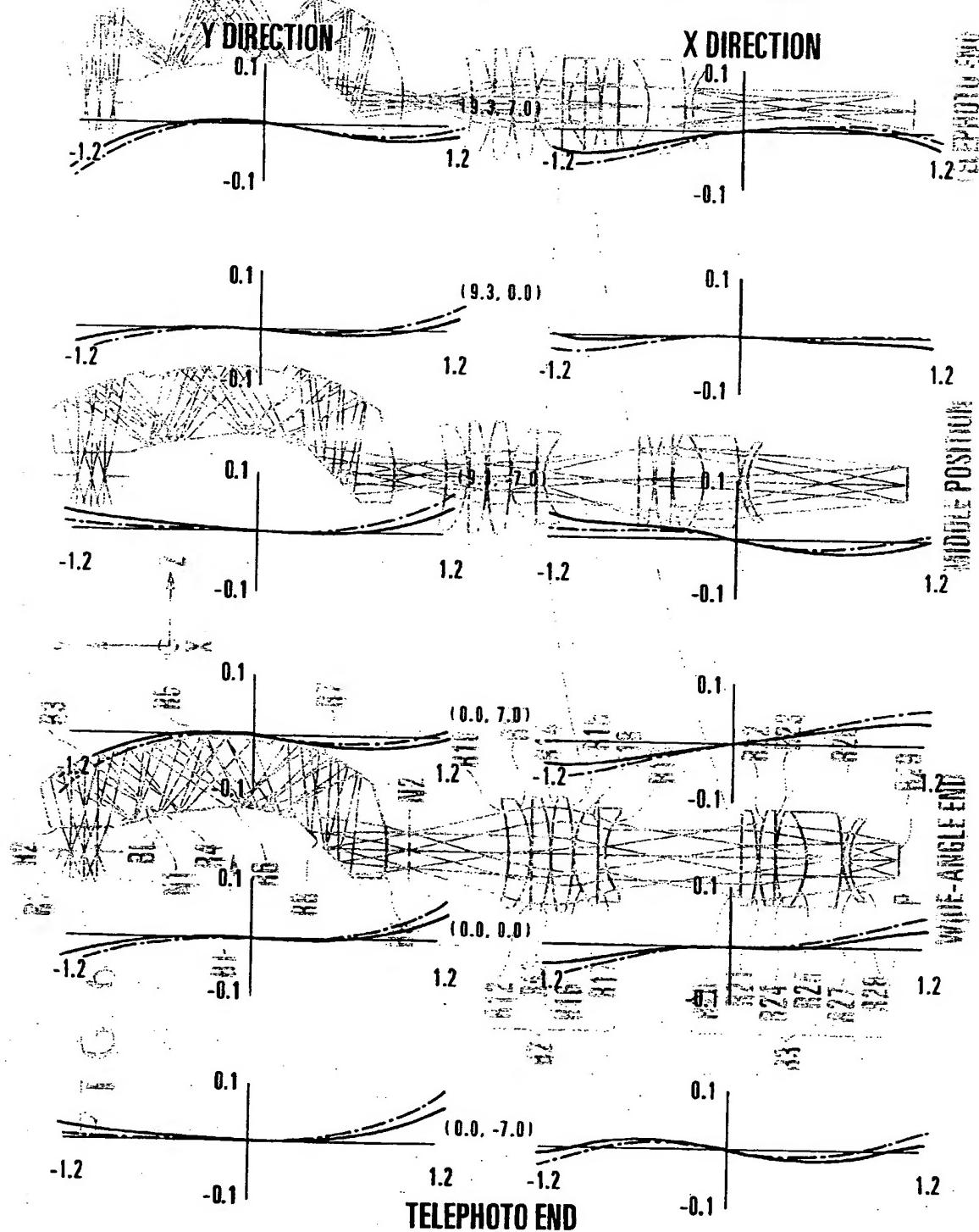


FIG. 10

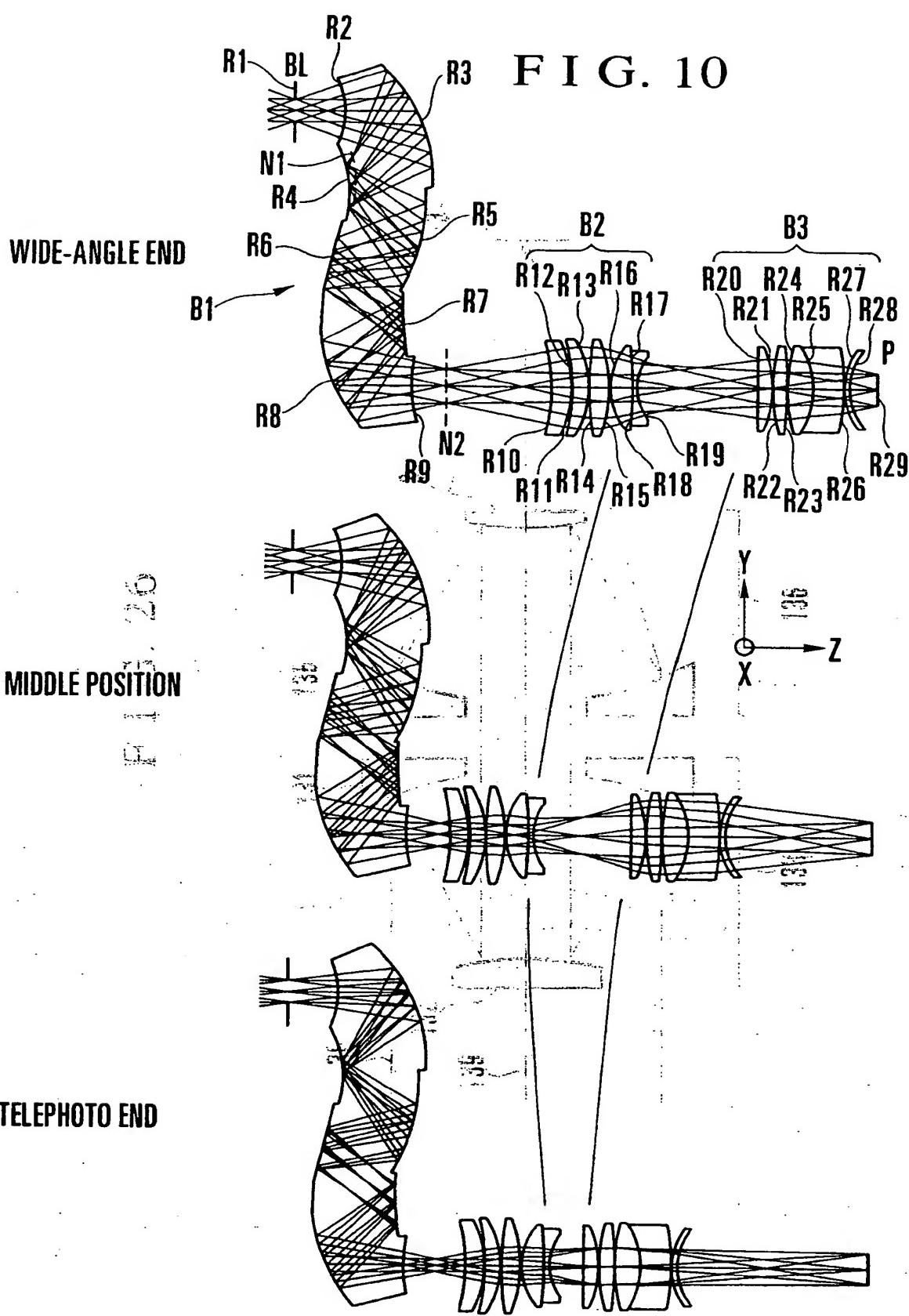
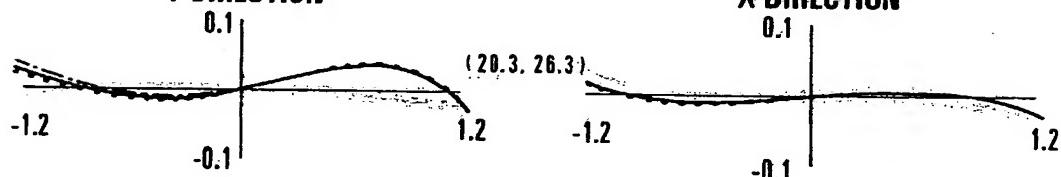


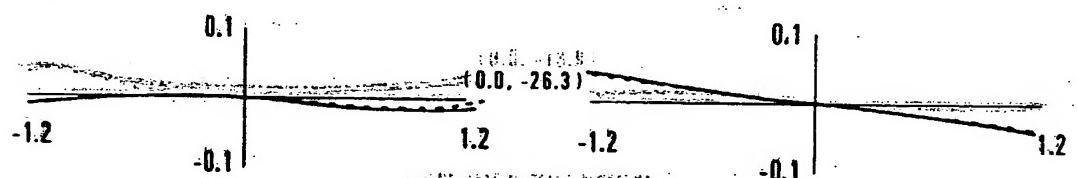
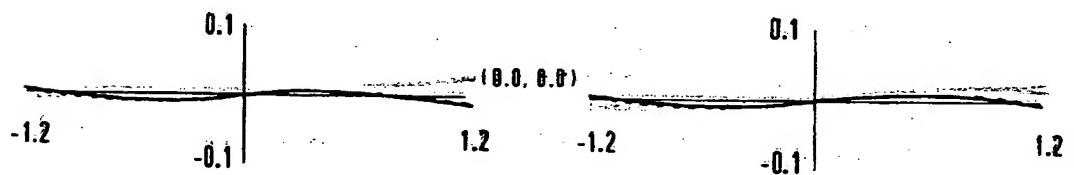
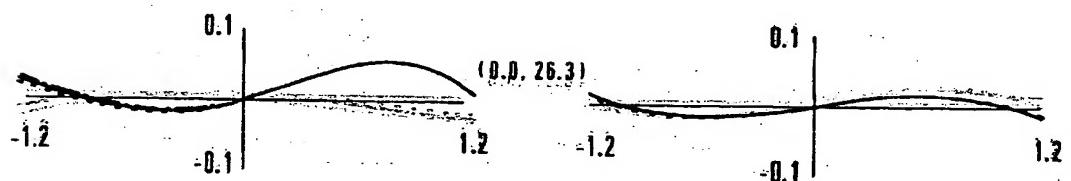
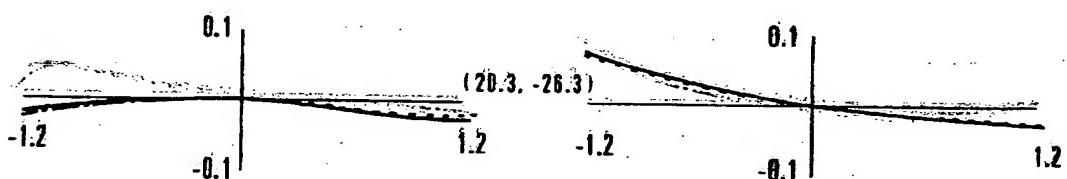
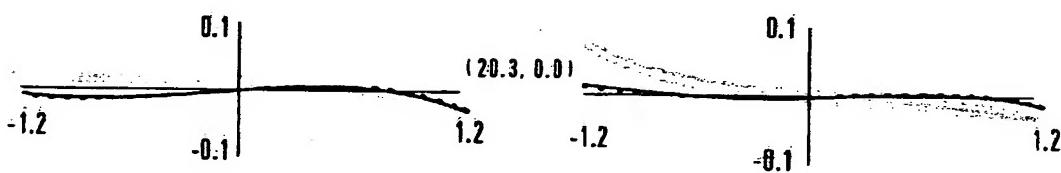
FIG. 14

(VERTICAL ANGLE OF VIEW, HORIZONTAL ANGLE OF VIEW)

Y DIRECTION



X DIRECTION



WIDE ANGLE END

FIG. 12

(VERTICAL ANGLE OF VIEW, HORIZONTAL ANGLE OF VIEW)

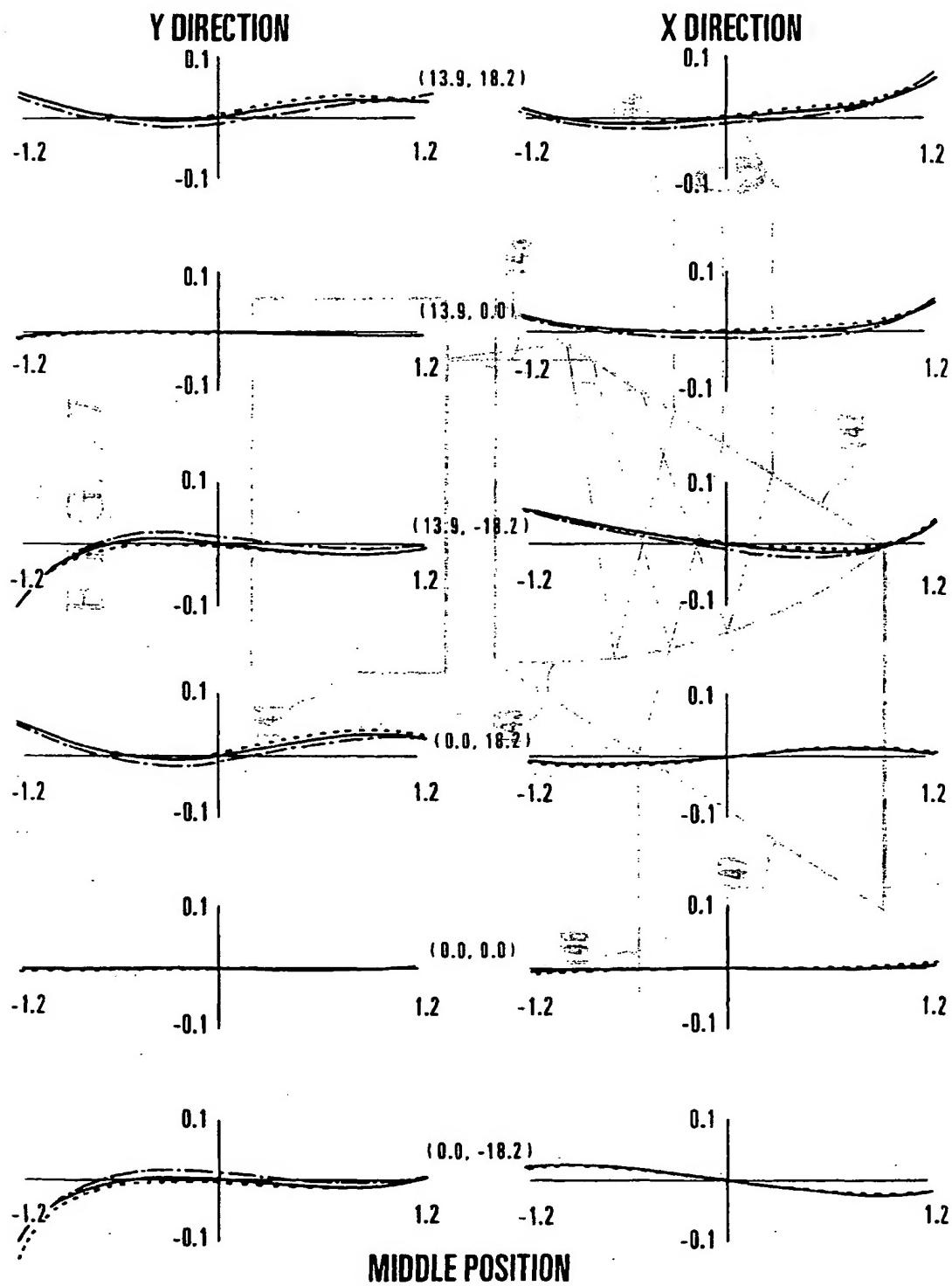


FIG. 13

(VERTICAL ANGLE OF VIEW, HORIZONTAL ANGLE OF VIEW)

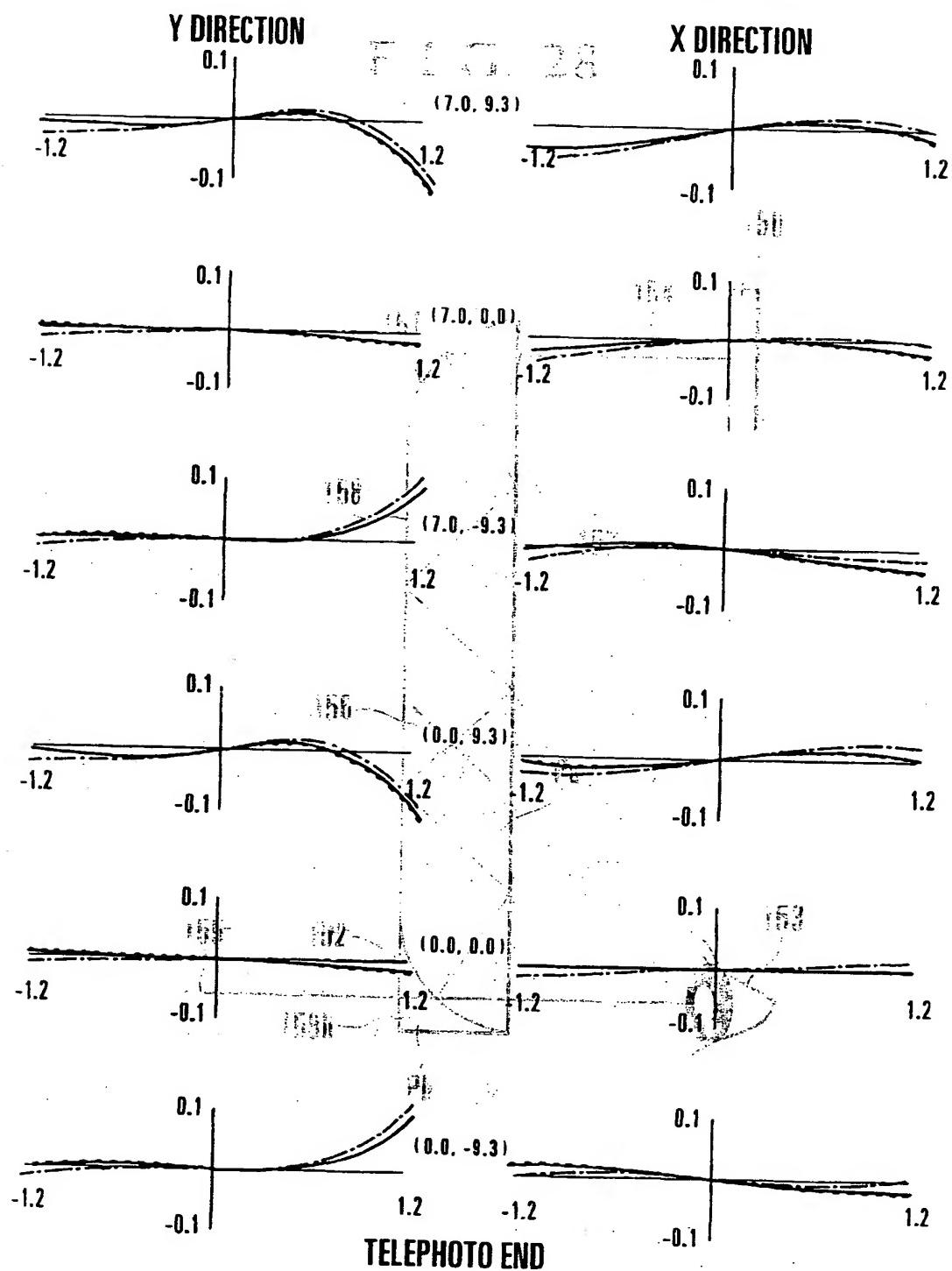


FIG. 32

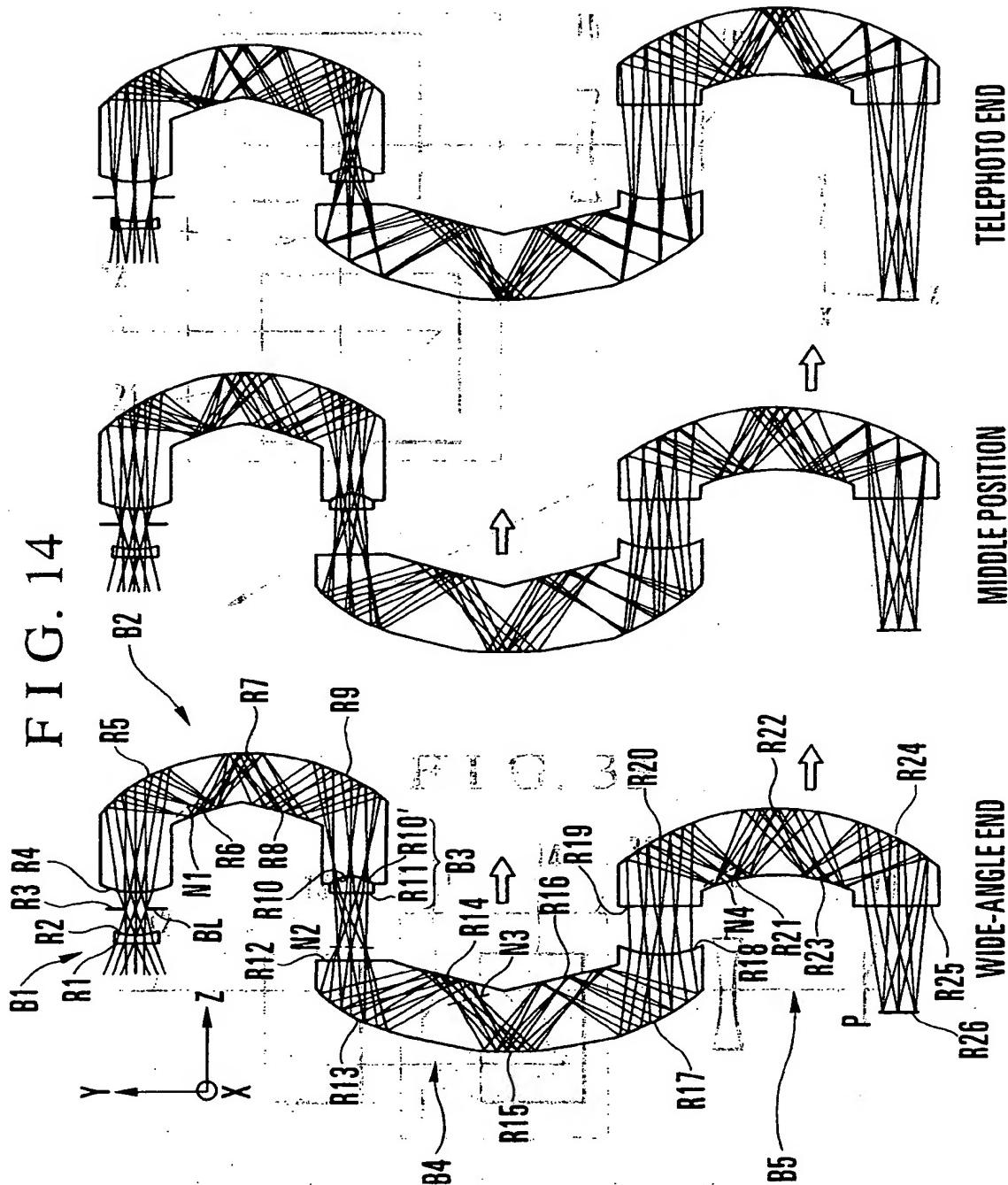


FIG. 15

(VERTICAL ANGLE OF VIEW, HORIZONTAL ANGLE OF VIEW)

Y DIRECTION

X DIRECTION

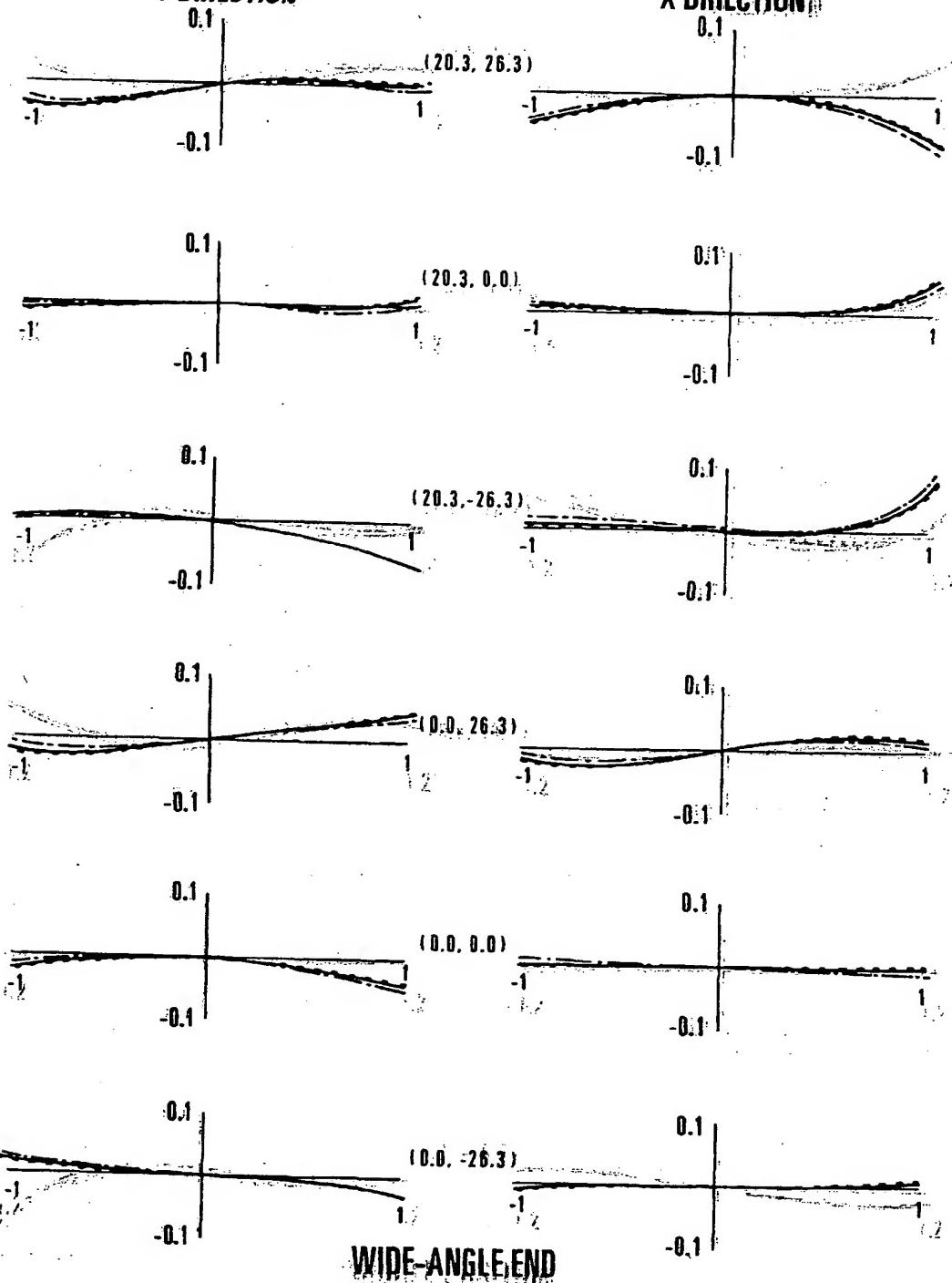


FIG. 16

(VERTICAL ANGLE OF VIEW, HORIZONTAL ANGLE OF VIEW)

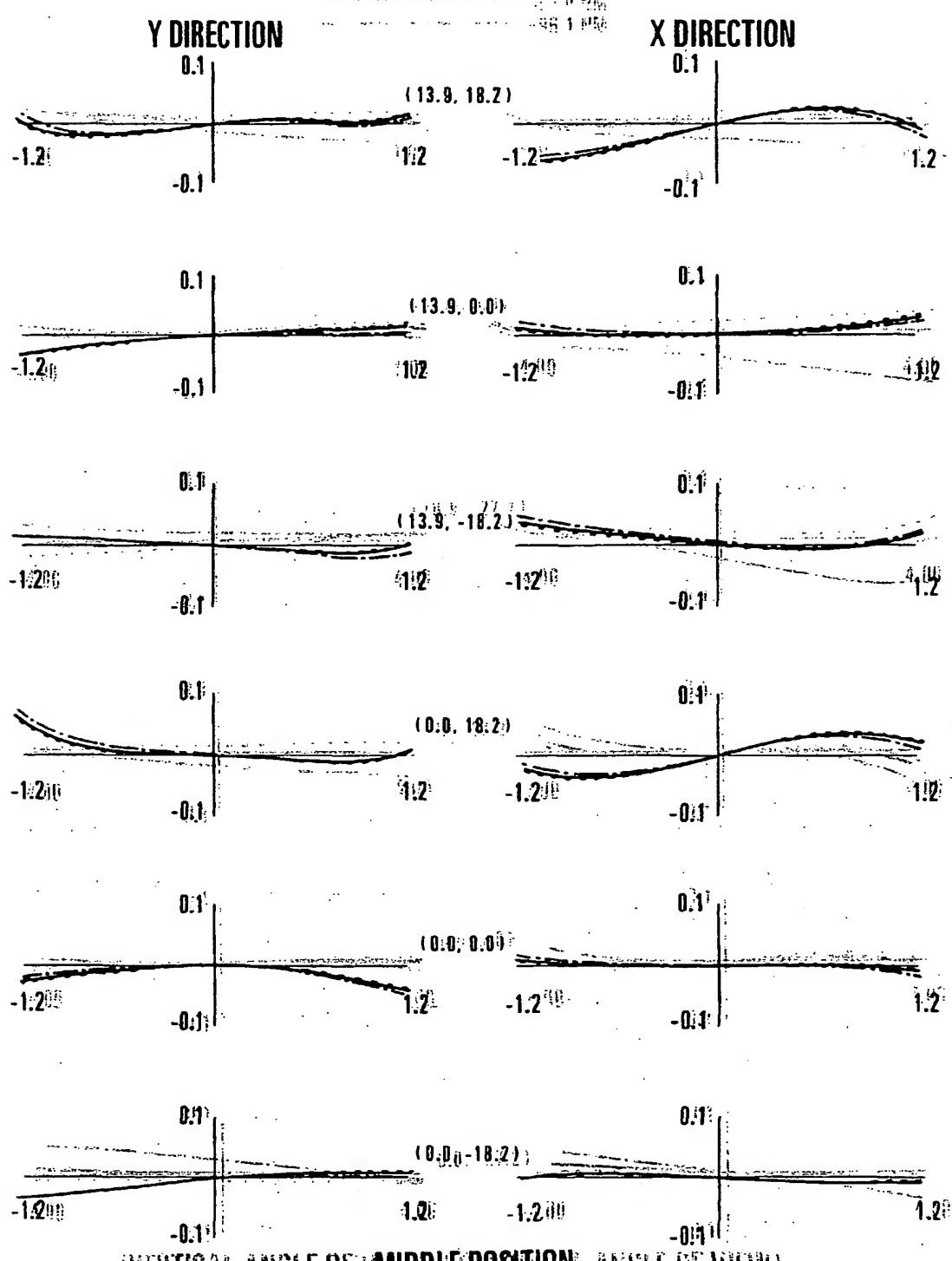


FIG. 17

(VERTICAL ANGLE OF VIEW, HORIZONTAL ANGLE OF VIEW)

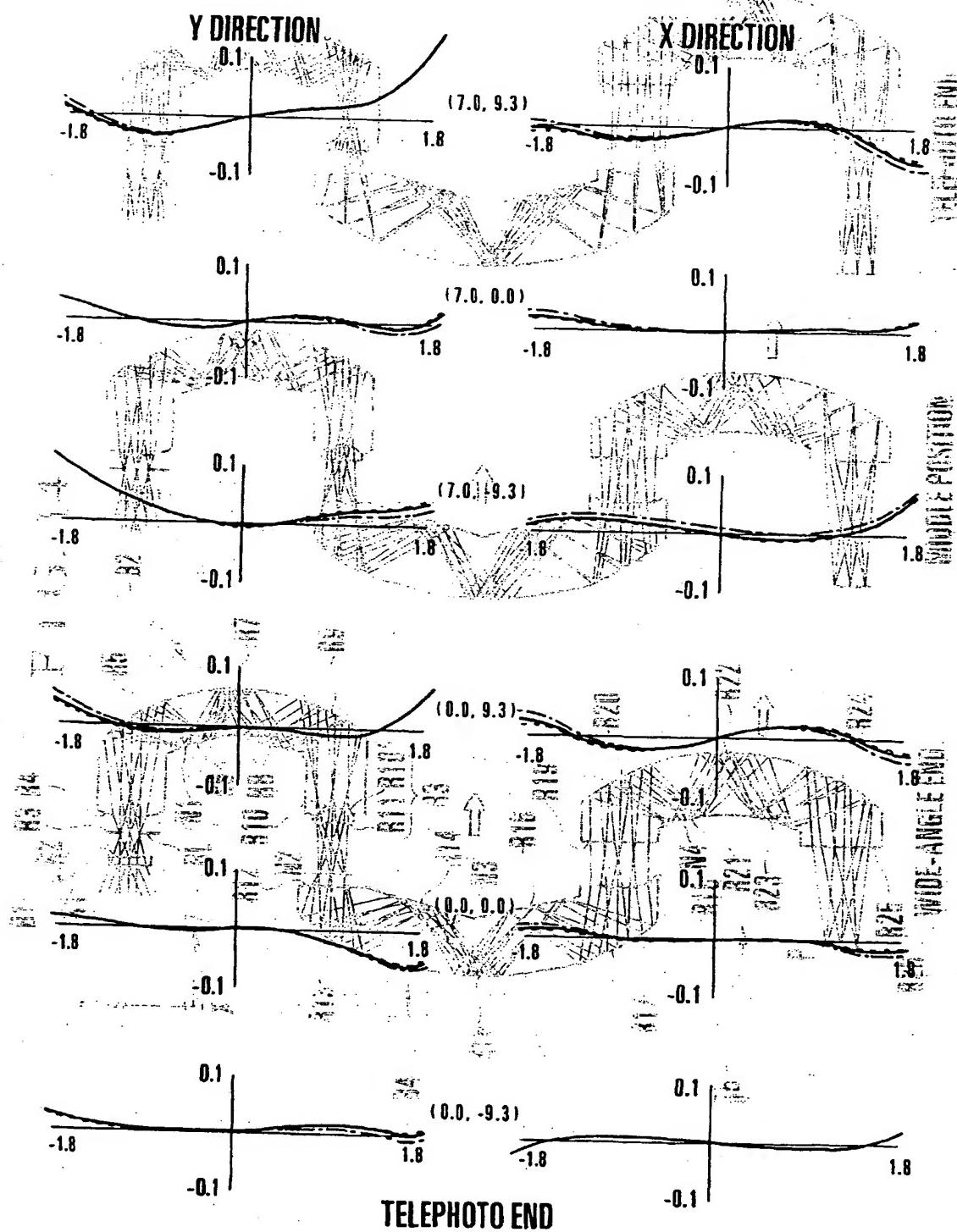
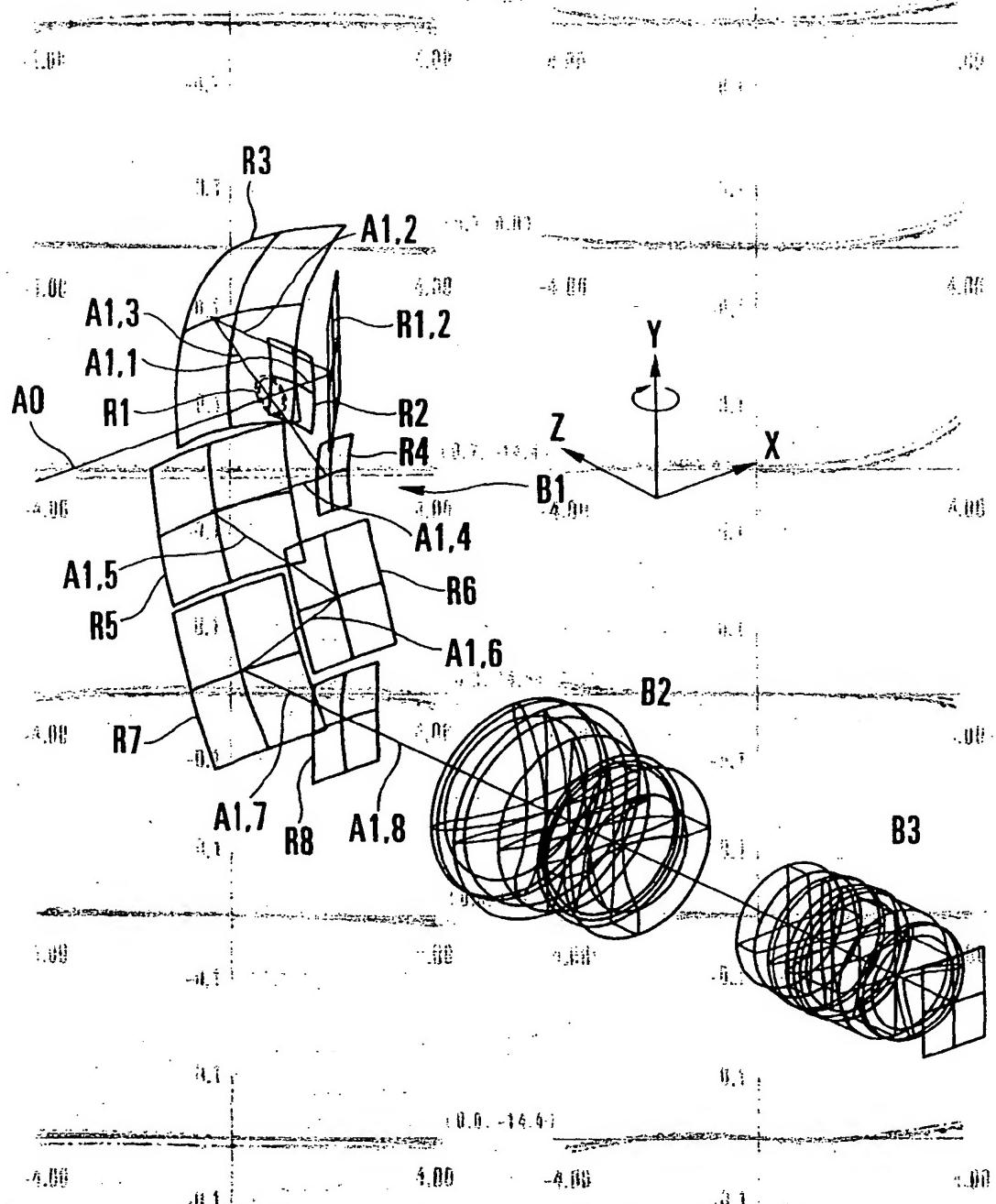


FIG. 39

500.4 B&W
507.8 RMS
426.1 DSC

FIG. 18



VERTICAL ANGLE OF VIEW, HORIZONTAL ANGLE OF VIEW

FIG. 19

VERTICAL ANGLE OF VIEW, HORIZONTAL ANGLE OF SWEEP

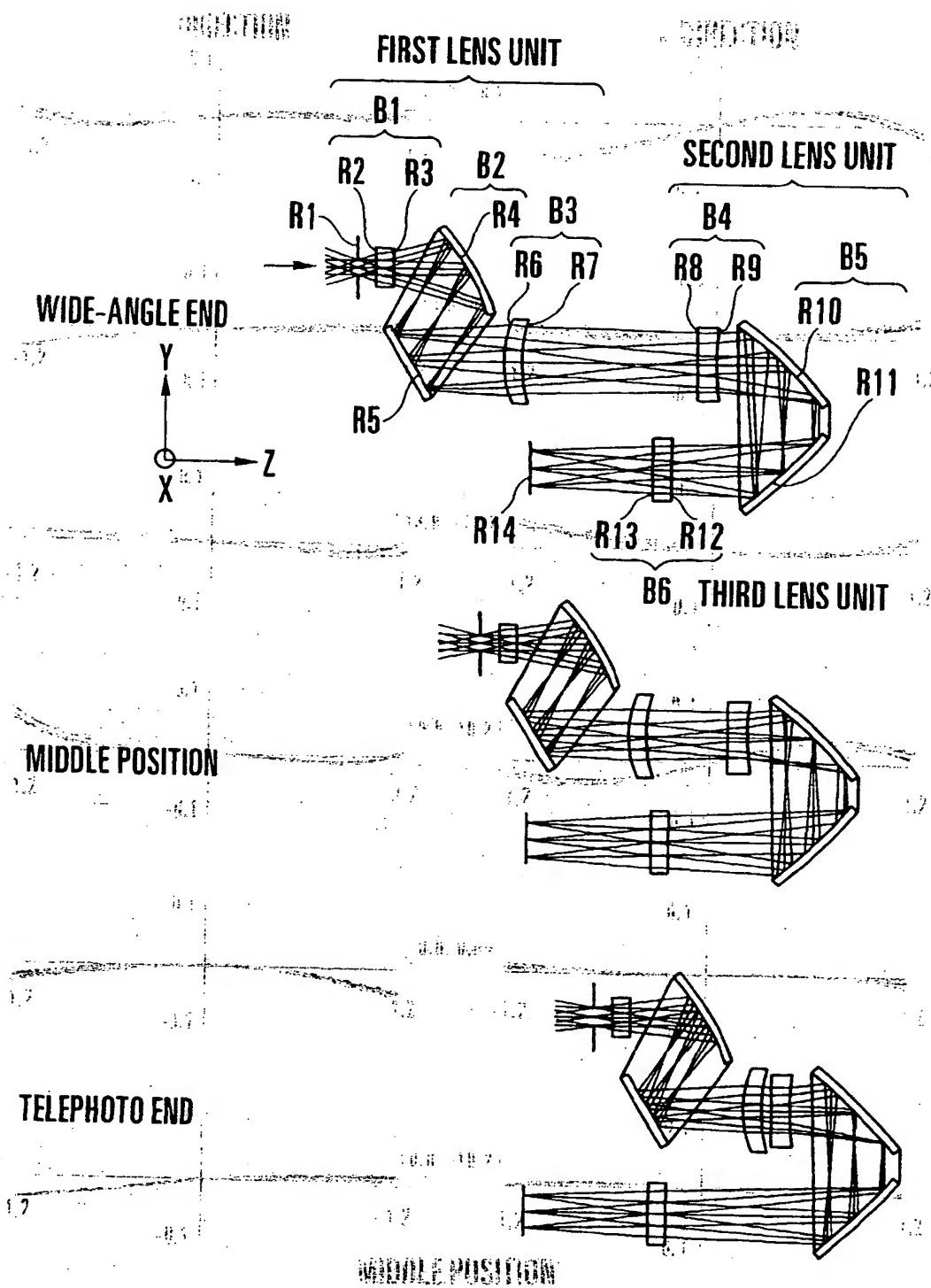
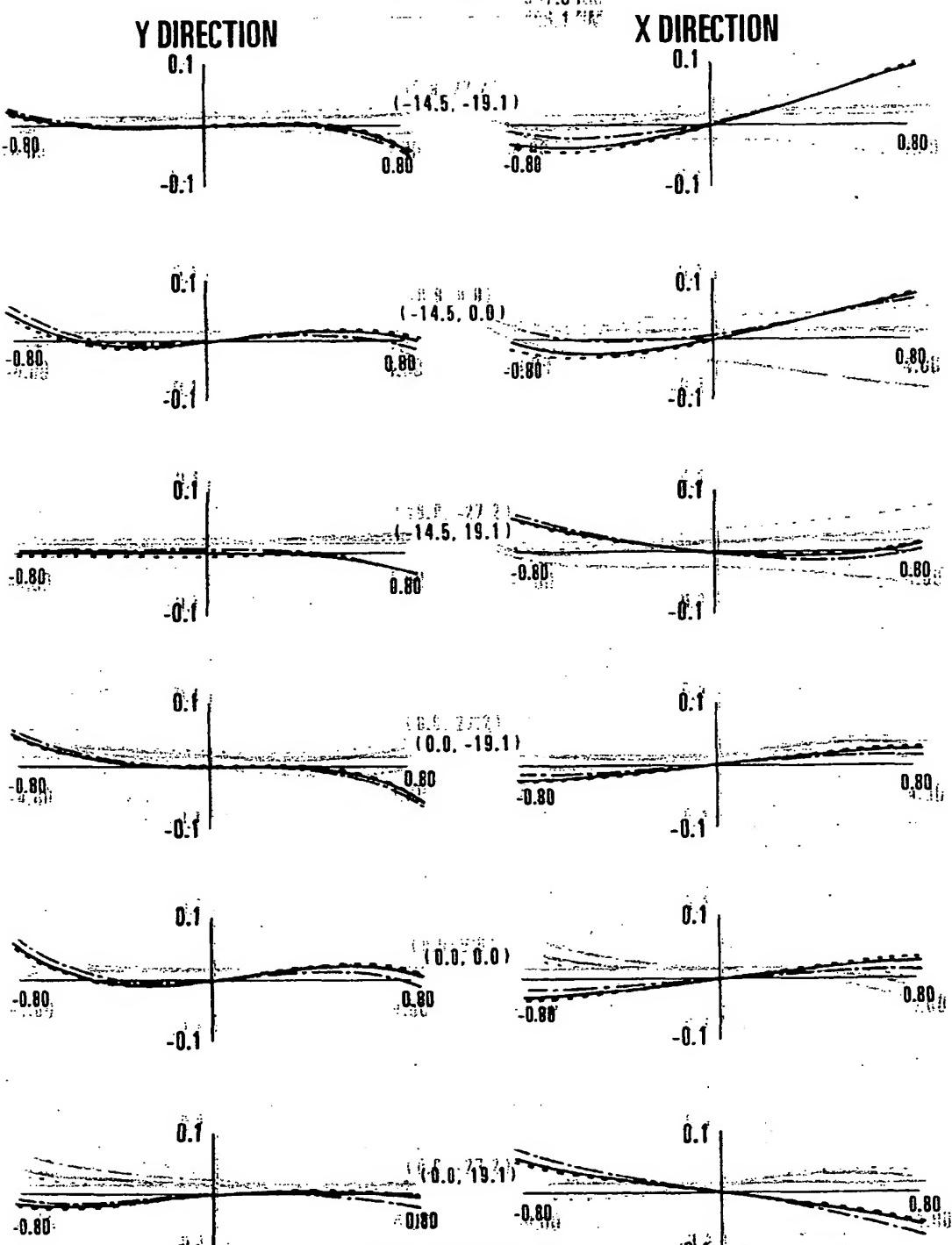


FIG. 203

(VERTICAL ANGLE OF VIEW, HORIZONTAL ANGLE OF VIEW)



(VERTICAL ANGLE OF WIDE-ANGLE END, HORIZONTAL ANGLE OF VIEW)

FIG. 21

(VERTICAL ANGLE OF VIEW, HORIZONTAL ANGLE OF VIEW)

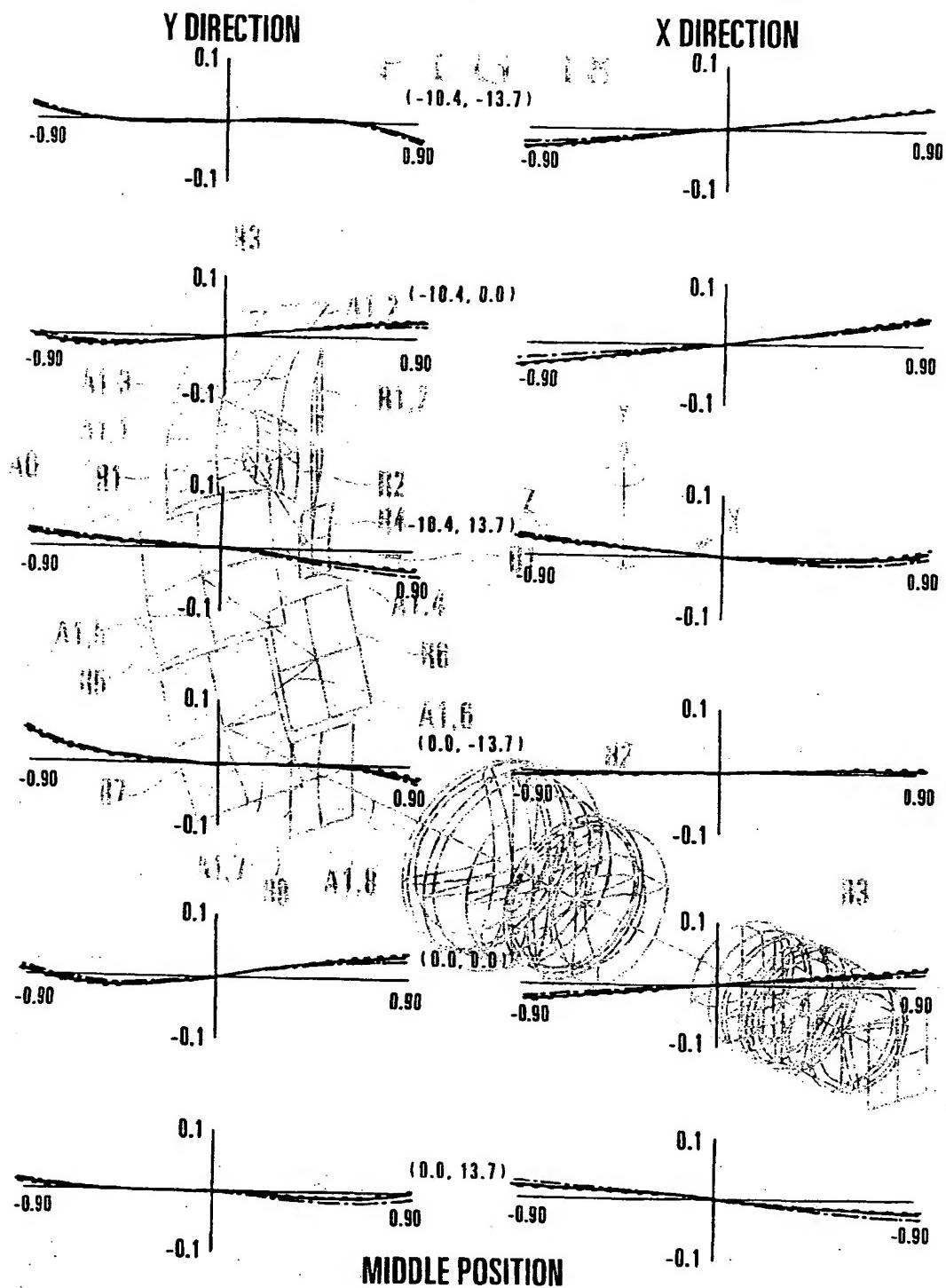
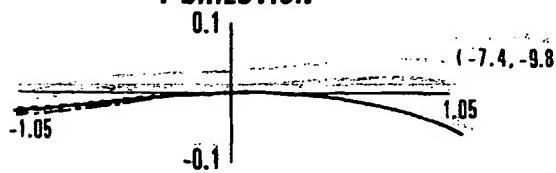


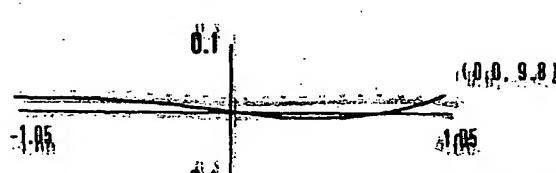
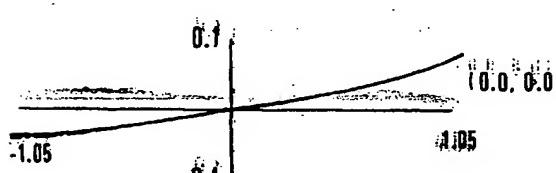
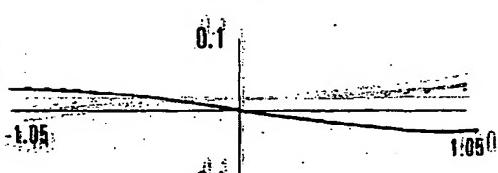
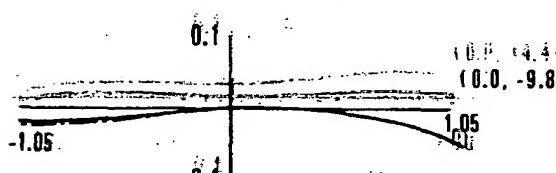
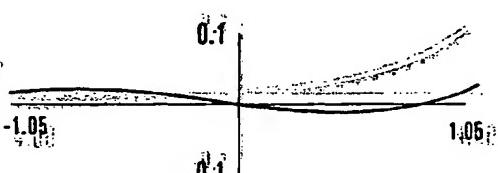
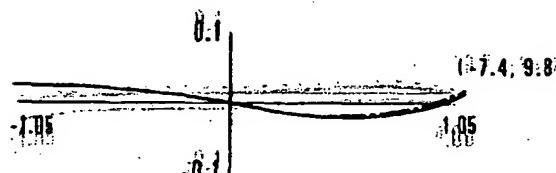
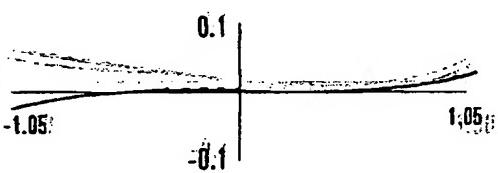
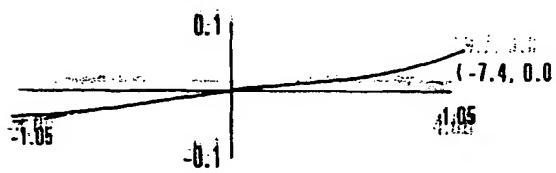
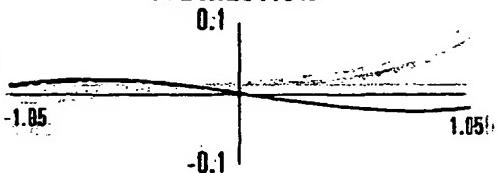
FIG. 422

(VERTICAL ANGLE OF VIEW, HORIZONTAL ANGLE OF VIEW)

Y DIRECTION



X DIRECTION



(VERTICAL ANGLE OF VIEW, TELEPHOTO END, HORIZONTAL ANGLE OF VIEW)

FIG. 20
FIG. 23

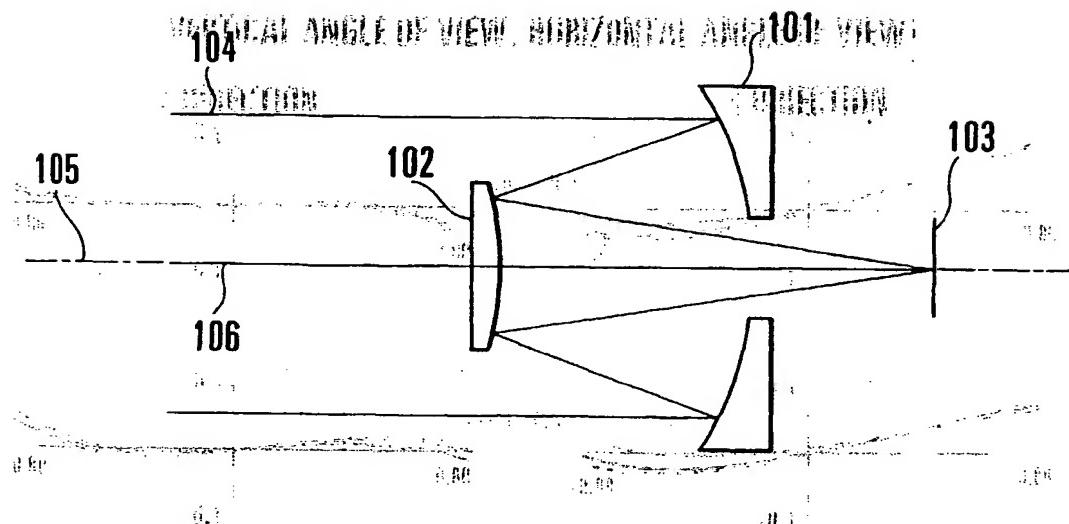


FIG. 24

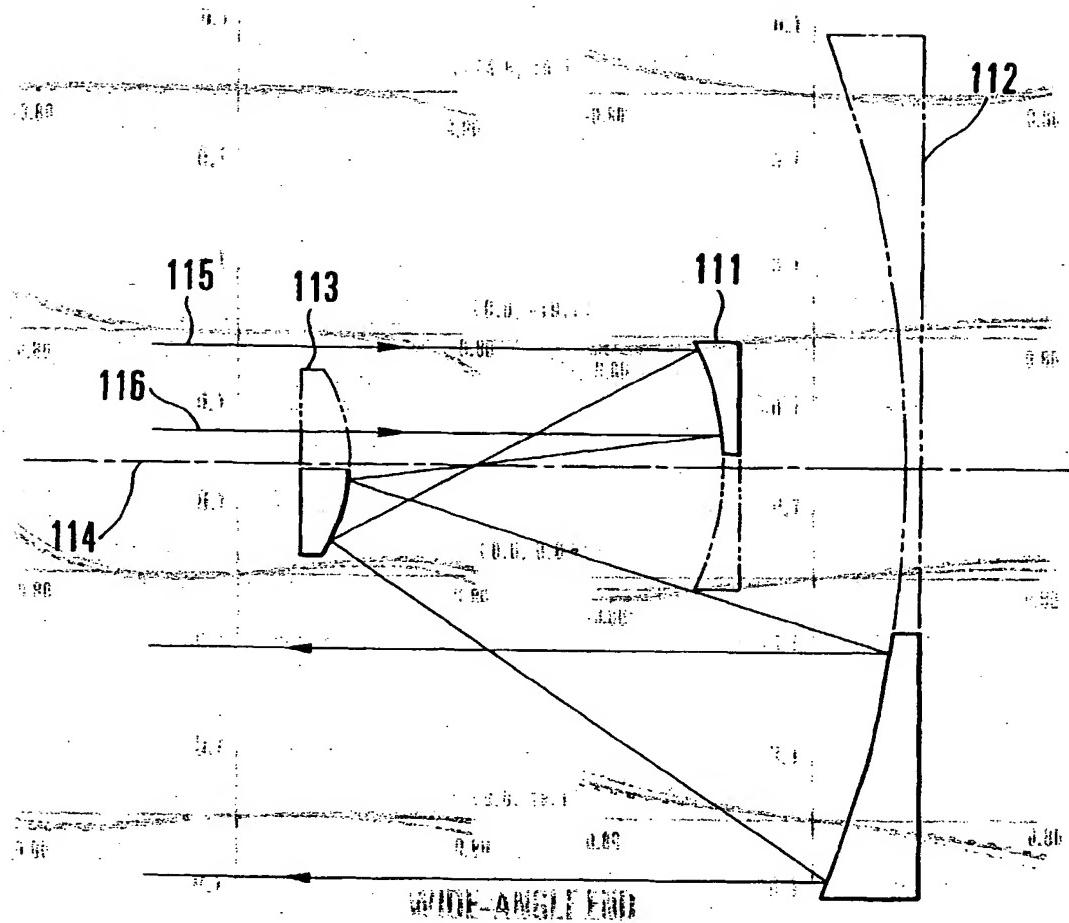
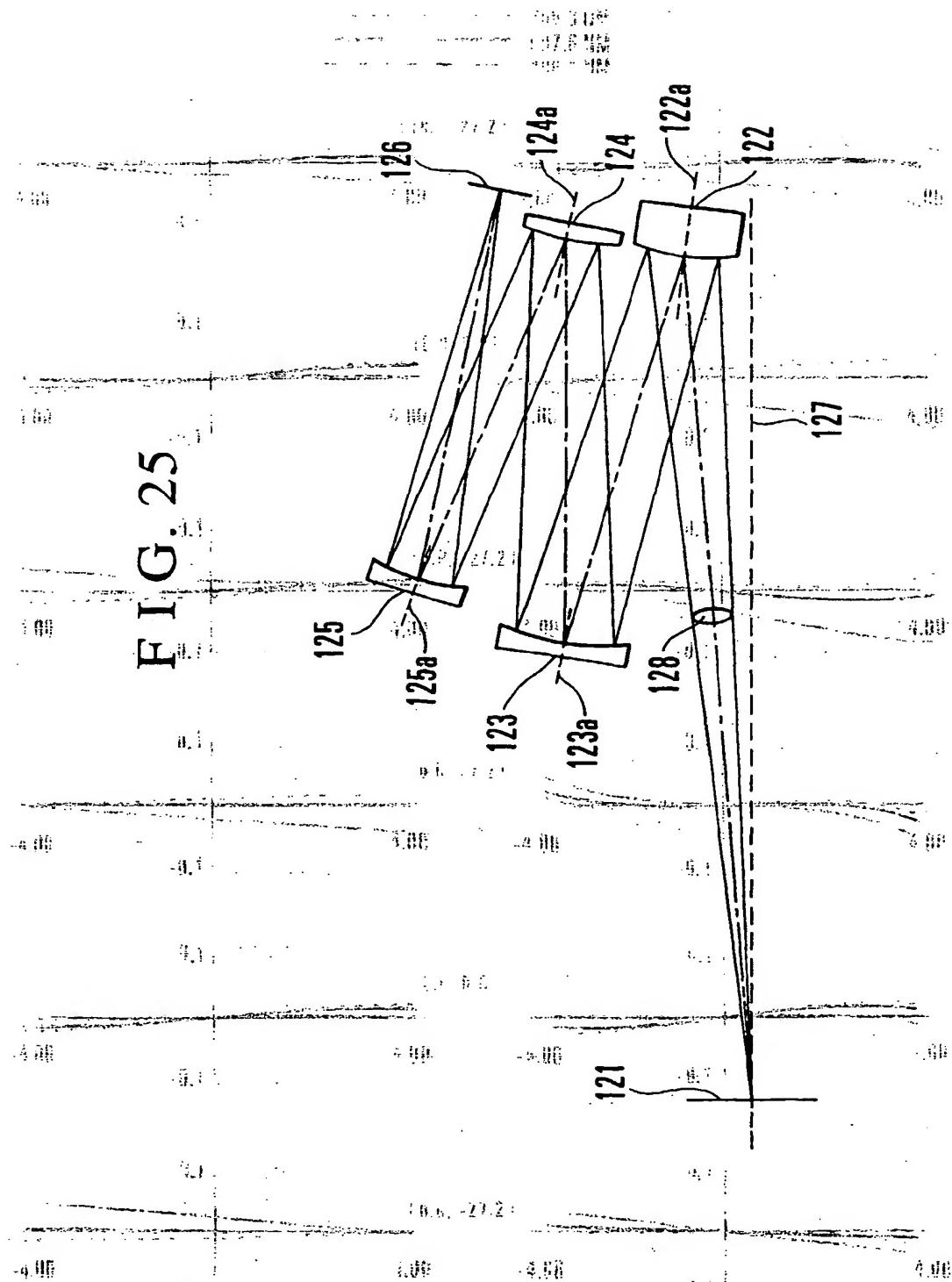


FIG. 25 46



$$\frac{d^2\psi}{dx^2} = \frac{B_1}{x^2}, \quad \frac{d^2\psi}{dy^2} = \frac{B_2}{y^2}, \quad \frac{d^2\psi}{dz^2} = \frac{B_3}{z^2},$$

HORIZONTAL ANGLE OF VIEW, HORIZONTAL ANGLE OF VIEW

卷之三

• 100 •

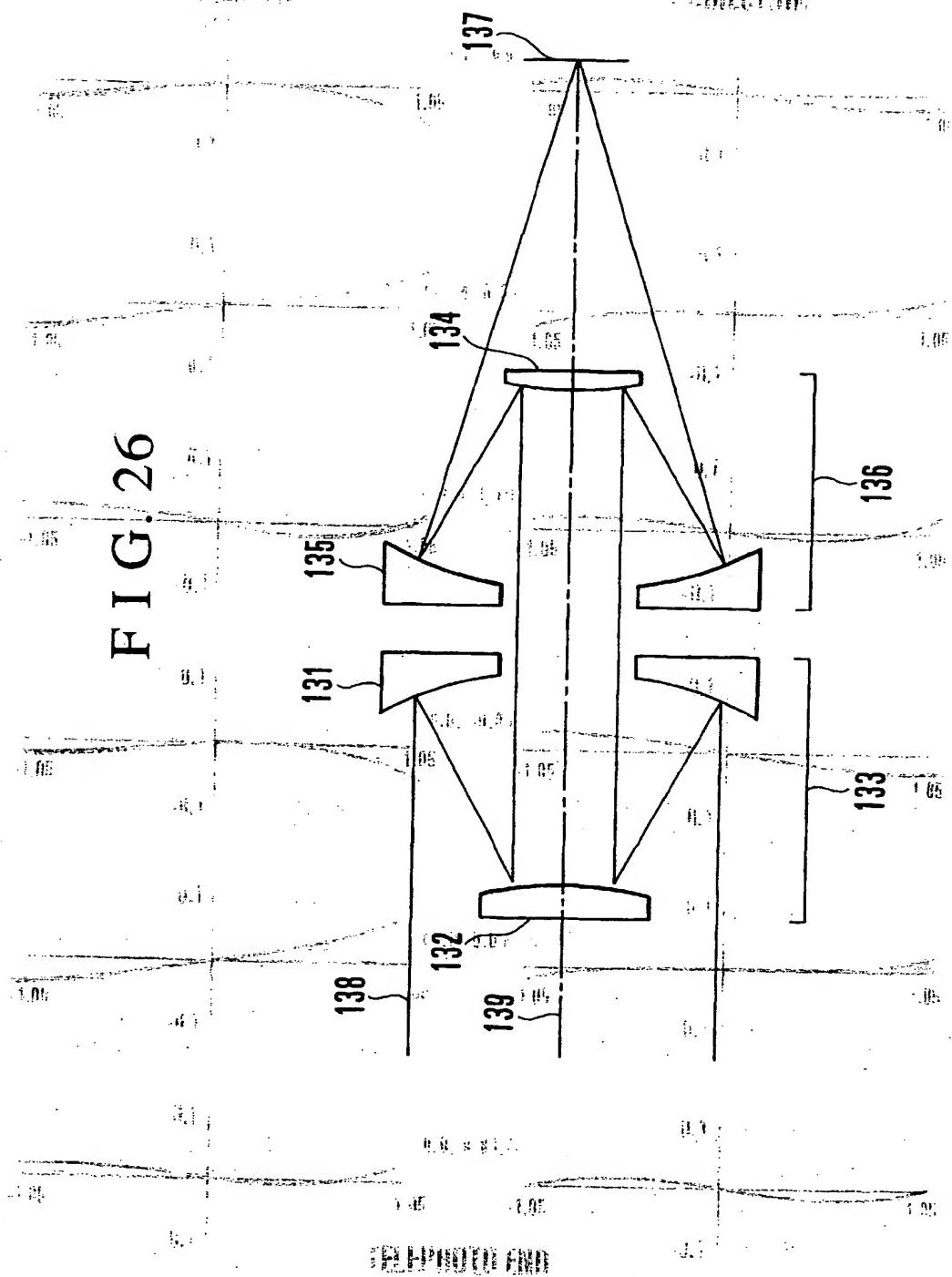
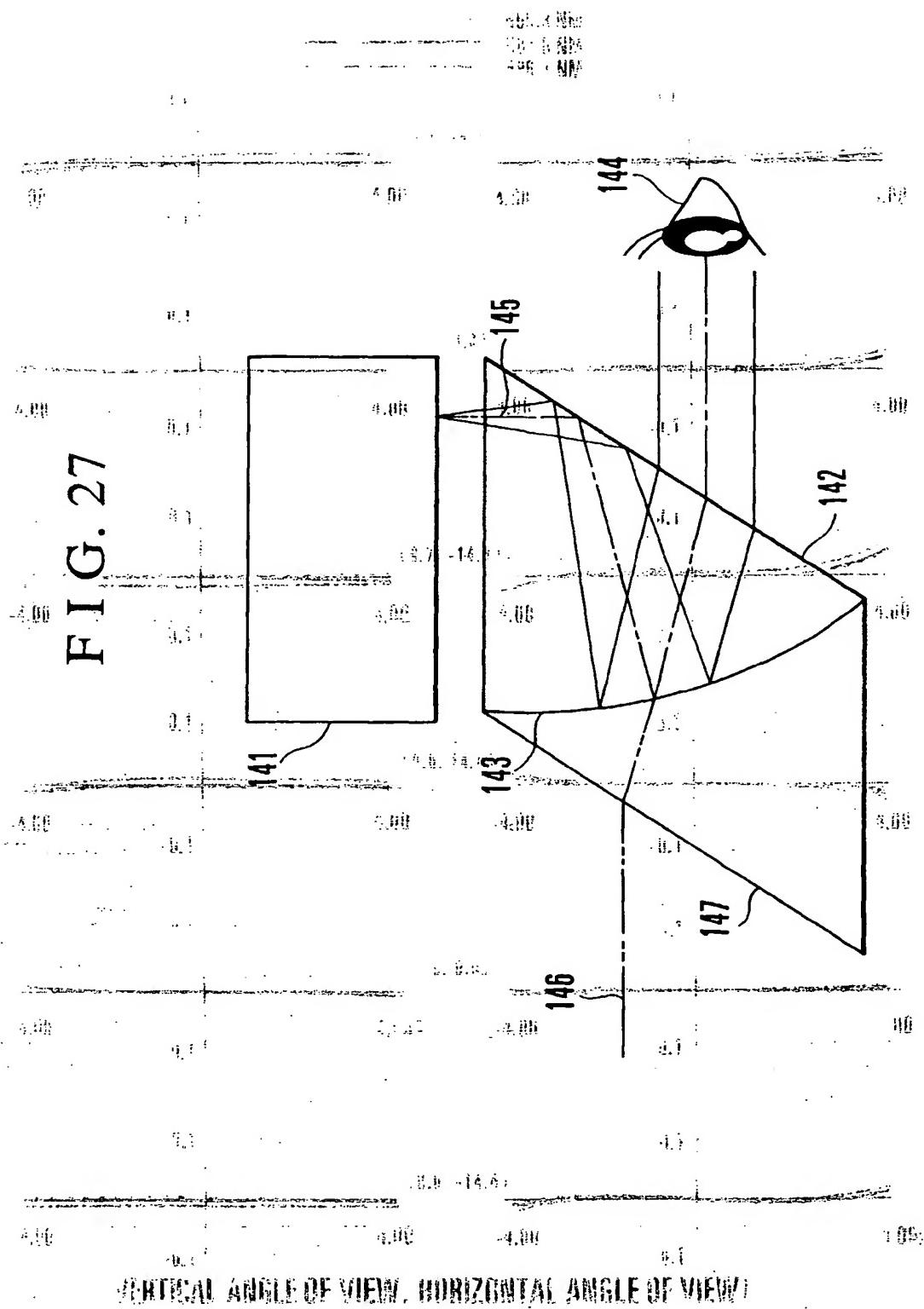


FIG. 51



F I G. 28

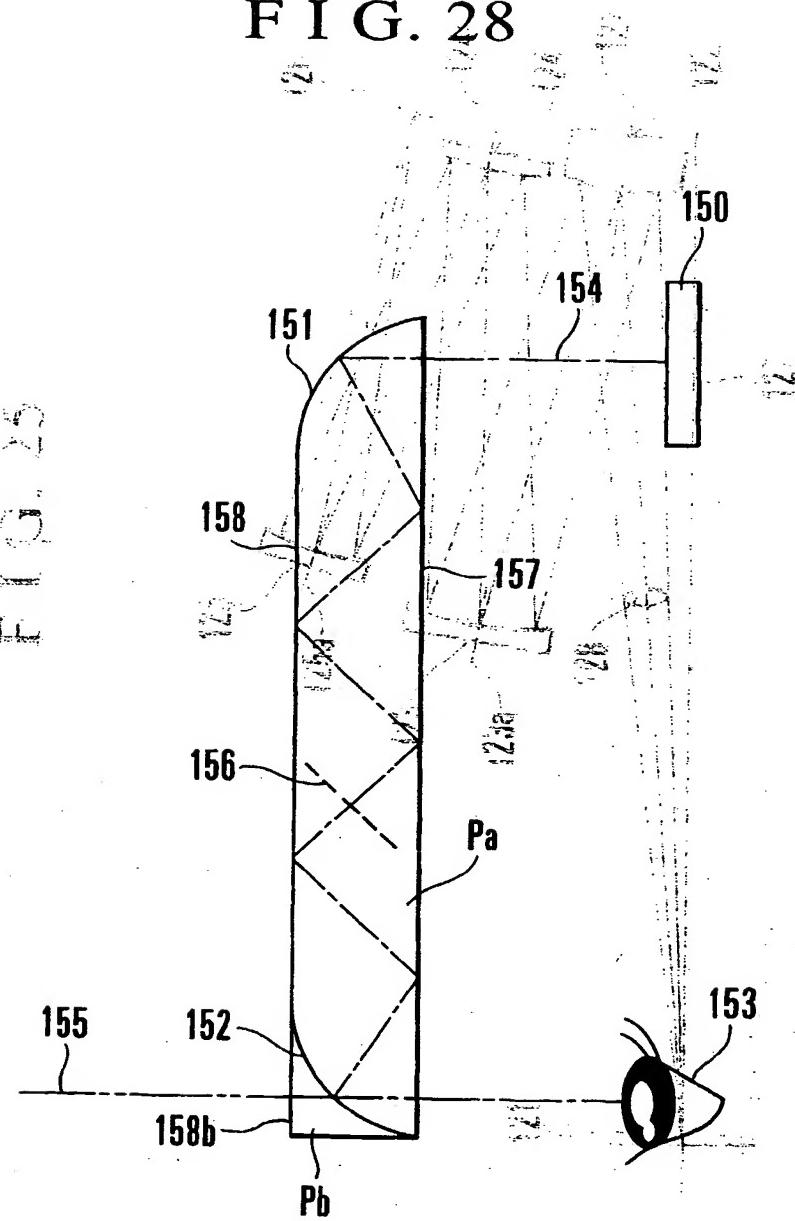
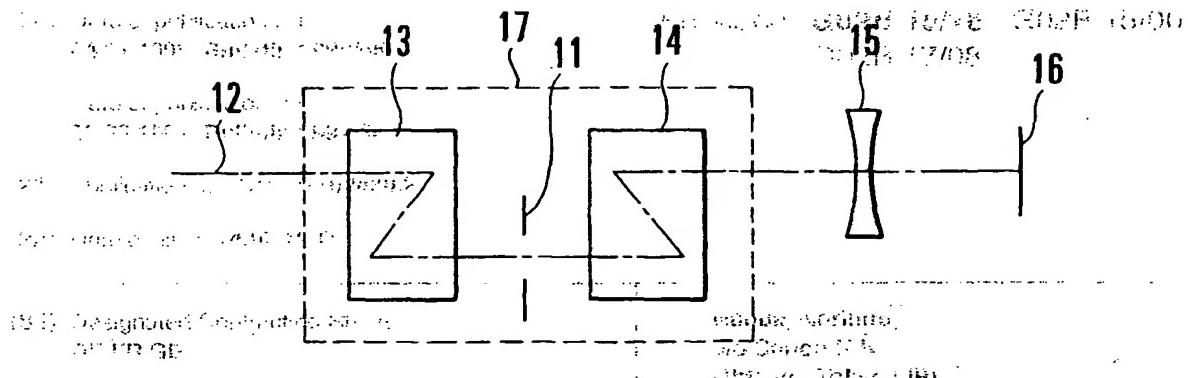


FIG. 29

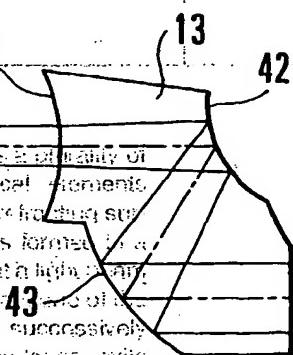
STEREOPHOTOGRAPHIC APPARATUS



(54) Application No. 93021533.3 filed 02/06/93
Priority date 02/06/93
(75) Inventor:
CANON KABUSHIKI KAISHA
Tokyo, Japan
(73) Inventor:
Akimasa Tatsuta,
Ph.D., Kyoto, Japan
Otsu-shi, Shiga, Japan
(56) Zoom lens

(57) A zoom optical system comprises a plurality of optical elements. The plurality of optical elements includes a first optical element having two refracting surfaces and a plurality of reflecting surfaces formed in a transparent body being arranged such that a light beam enters an edge of the transparent body from 43 and of the two refracting surfaces and after being successively reflected from the other of the two refracting surfaces, and/or a second optical element having a plurality of surfaces, each being formed and decentered relative to one another, being arranged such that an incident light beam using theretofore after being successively reflected from a reflecting surface in the plurality of reflecting surfaces and/or a second optical element forms an image of an object at a position 41 and 42 and 44 respectively, thereby facilitating an exchange of the optical elements and improving the optical characteristics of the plurality of optical elements.

FIG. 30



(54) Application No. 93021533.3 filed 02/06/93
Priority date 02/06/93
(75) Inventor:
CANON KABUSHIKI KAISHA
Tokyo, Japan
(73) Inventor:
Akimasa Tatsuta,
Ph.D., Kyoto, Japan
Otsu-shi, Shiga, Japan
(56) Zoom lens

(57) A zoom optical system comprises a plurality of optical elements. The plurality of optical elements includes a first optical element having two refracting surfaces and a plurality of reflecting surfaces formed in a transparent body being arranged such that a light beam enters an edge of the transparent body from 43 and of the two refracting surfaces and after being successively reflected from the other of the two refracting surfaces, and/or a second optical element having a plurality of surfaces, each being formed and decentered relative to one another, being arranged such that an incident light beam using theretofore after being successively reflected from a reflecting surface in the plurality of reflecting surfaces and/or a second optical element forms an image of an object at a position 41 and 42 and 44 respectively, thereby facilitating an exchange of the optical elements and improving the optical characteristics of the plurality of optical elements.

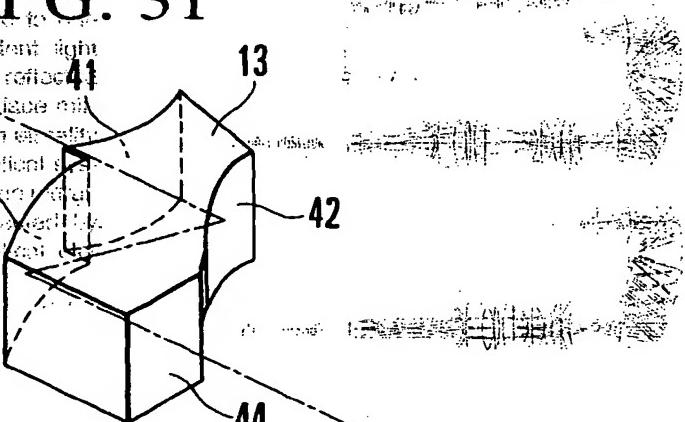


FIG. 32

European Patent Office

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EUROPEAN SEARCH REPORT

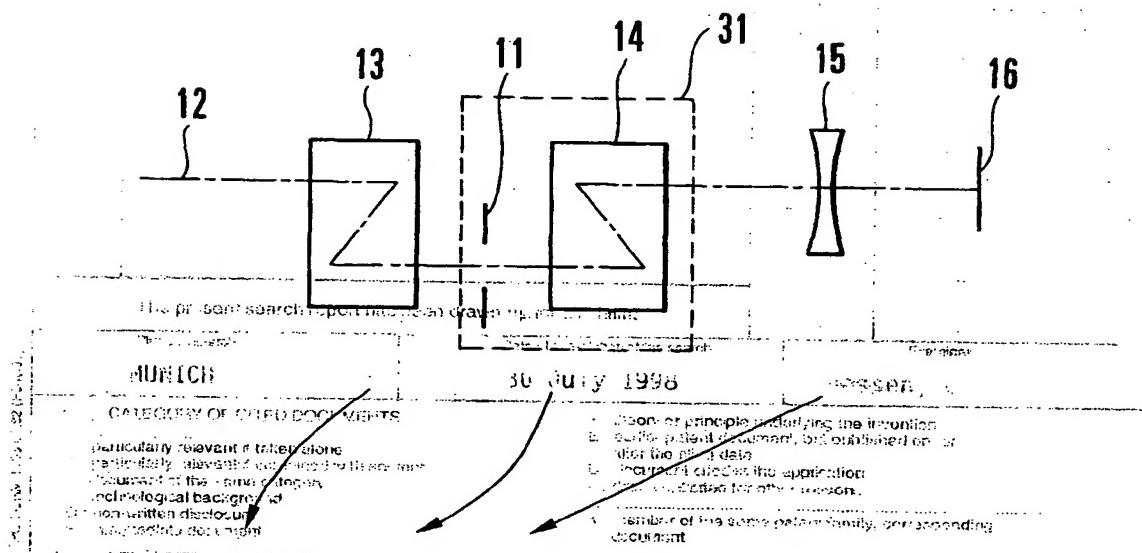
Application Number
EP 0 790 513 06

DOCUMENTS CONSIDERED TO BE RELEVANT				16	CLASSIFICATION OF THE APPLICATION (B6CL6)
22	US-A-5 64 764 CINNAMYL ALCOHOL 26.3.97 November 1997 Chemical group	11	US-A-5 64 764 CINNAMYL ALCOHOL 26.3.97 November 1997 Chemical group	12	002B15/15 002R15/00 C28C7/00
11	EP-A-0 712 136 CANNON KEP 1 30.11.1996 Figure 1-3	12	EP-A-0 712 136 CANNON KEP 1 30.11.1996 Figure 1-3	13	12-14
21	US-A-5 237 773 A CANON DRUGER 17.7.1993 abstract: figures 1,2 *	21	US-A-5 237 773 A CANON DRUGER 17.7.1993 abstract: figures 1,2 *	14	15-20
22	EP-A-0 730 160 A CANON KEP 4 September 1996 the whole document *	22	EP-A-0 730 160 A CANON KEP 4 September 1996 the whole document *	15	16

Y
X
Z

TECHNICAL FIELDS SEARCHED (B6CL6)
G02R

FIG. 33



159

PERIODICALS RECEIVED IN THE MONTH OF APRIL

FIG. 34

Instrument 10 - **Stages I** - **z**-scanning optical systems and image pickup apparatus using **R1** to **R12** reflectors. Optic system 10 which comprises a plurality of optical elements of two types, one of which has a plurality of reflecting surfaces **R1** to **R12** and the other of which has a plurality of refracting surfaces **R2** to **R8**. A portion of the plurality of optical elements in each of the two types of elements is arranged to receive light from a source of illumination and to project light through a lens system 11 to a specimen stage 12. The other portion of the plurality of optical elements in each of the two types of elements is arranged to receive light from the specimen stage 12 and to project light through a lens system 13 to an image pickup device 14.



The other optical coefficients for BBR fibers are also plotted in Fig. 10. The values of the refractive index along the fiber axis are the same as in the case of the uniaxial birefringent fiber.

In addition to having planar surfaces, there may be curvature present imposed for utilizing reflecting surfaces such as convex or concave mirrors. It has been disclosed to provide an optical system which makes use of a reflecting system and a refracting system in conjunction. The system is well known as the catadioptric system.

Fig. 2. Schematic diagram of an optical system consisting of two positive lenses and two convex mirrors or two concave mirrors optical system.

FIG. 35

This major optical system is based on the *catadioptric* effect of the *Wright* type of reticulating telescope. The aim of adopting it is to shorten the total length of the entire optical system compared with the long physical length of the refracting telescope, i.e., the optical path is folded by using two reflecting mirrors as *prisms* in *crossed* reflection.

even for the objective term, certain constituents part of it may not operate for the same reason. The *adverbial type* in which many other types have come to be known which differ in the function and the co-ordination of the adverbial phrase of offending verbs, in order to cover more sharply the meaning of the A. 4 rule.

The following effect has been made to facilitate the taking of the picture. The camera is held very long. For this purpose, instead of the use of its long extension tube, it is recommended to use a tripod, which will easily pick up the optical sight. A tripod

In the Cassegrain-type reflecting telescope, the primary mirror is studied in part. This is attributable to the fact

the present situation, the best way to proceed is to have the author to make his proposal.

To solve this problem, the FOV_1 may be decomposed, and a portion of the FOV_1 or a sub-image of the object high resolution may be cleared of the obscuration of the other parts of the optical system. In other words, the principal part FOV_1 of the object field beam FOV is set off from an optical axis AOI . Such a mirror optical system, or MOS , has previously been proposed.

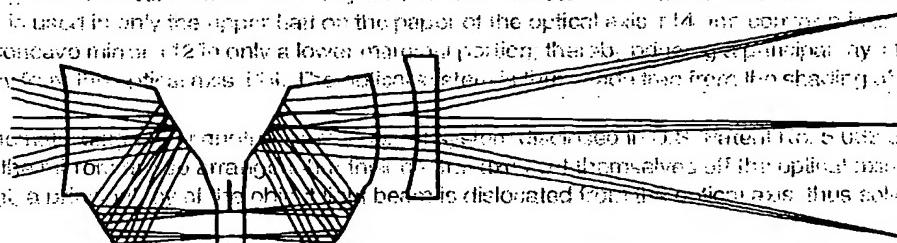
Fig. 24 is a schematic diagram of a mirror optical system disclosed in U.S. Patent No. 3,674,334, which has sole

FIG. 36 A photograph of a resolution test chart with a resolution of 1000 lines per mm.

The optical system shown in Fig. 23 comprises in the order in which the light beam encounters them a convex lens 111, a convex mirror 110 and a concave mirror 112. In the prototype design, these are of the forms shown by the double-headed and single-headed arrows. An arrowhead symmetrizes respect to the optical axis 114. In actual practice, the concave mirror 112 is used in only the upper half of the paraxial axis 114, the convex lens 111 in only the lower half and the concave mirror 112 in only a lower change of position, thereby reducing a principal ray 118 of the object light 116 away from the optical axes 114. The optical system is formed from four thin shading of the object light beam 115.

Fig. 95 shows how the lenses are arranged in the system described in U.S. Patent No. 2,038,306, in the rear optical system. The lenses are arranged so that they do not fall off themselves off the optical path of the system. By this arrangement, a displacement of the objective lens bed will dislodge the lenses from the axis, thus solving the above-described problem.

In Fig. 26, an object to be imaged is shown in front of a plane 121. Assuming that a line perpendicular to the plane 121 is an optical axis 127 it is found that, as the light beam encounters a convex mirror 122, a concave mirror 123, a convex mirror 124 and a concave mirror 125 successively in this order, the centers of curvature of their reflecting surfaces and their optical axes (the lines connecting those centers with the respective centers of curvature of those reflecting surfaces)



F I G. 37

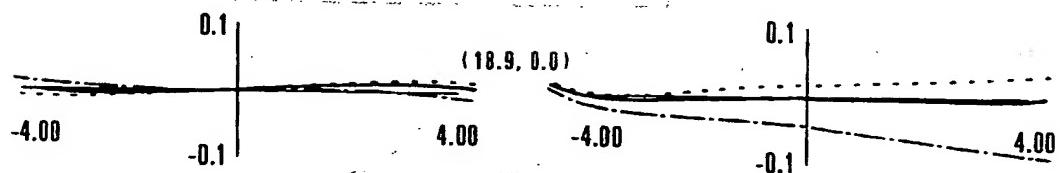
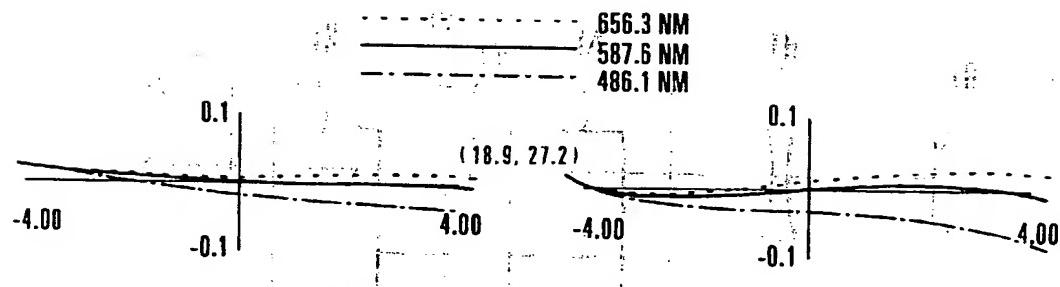


FIG. 30
(18.9, -27.2)

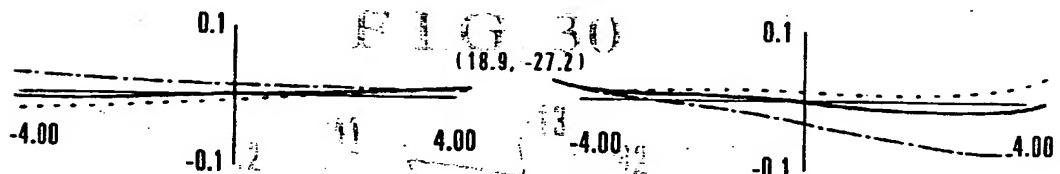


FIG. 30
(0.0, 27.2)

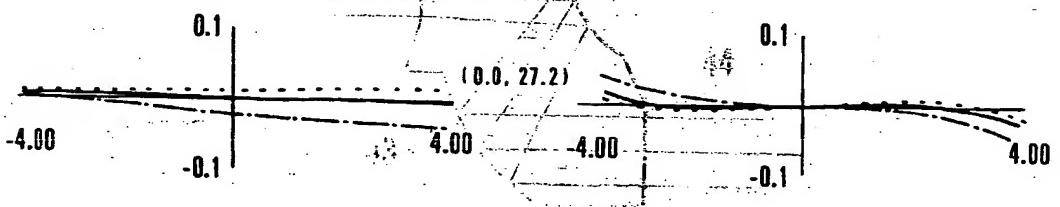


FIG. 31
(0.0, 0.0)

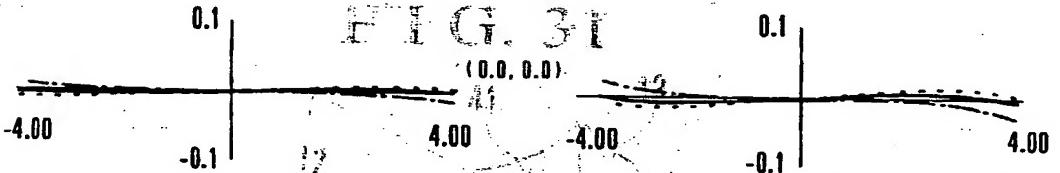
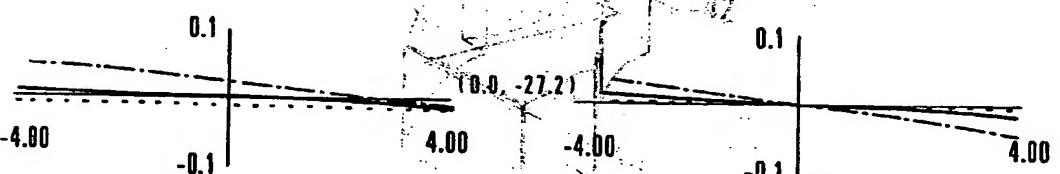


FIG. 31
(0.0, -27.2)



(VERTICAL ANGLE OF VIEW, HORIZONTAL ANGLE OF VIEW)

14.2. entering the place "in" of the object - so the observer remains
not fixed or telescope.

FIG. 38 Schematic diagram showing the configuration of the laser oblique projection system described in Japanese and German Patent Application No. Toku 2-275136. The laser optical system (LCS) is used for viewing the external light source through the lens, at the same time, it projecting information on the display device as OVC, tapping the wire.

The country right before the target was covered up a covering began from the top of the hill to the left of the target. The men proceeded to walk along the surface of the ground, and as they did so, an ordinary-looking ant hill came into view. The men stopped to look at the ant hill, and as they did so, the ant hill exploded, sending a cloud of smoke and dust over the men. The men then continued on their way, and as they did so, the ant hill exploded again, sending another cloud of smoke and dust over the men. This happened several times, until the men reached the bottom of the hill, where they found the target.

Mean value of the object height measured with the external field passes through a flat surface with a curvature of 10° , the observer's eye lies at the height of 1.65 ± 0.05 m above the ground, the distance between the station and the observer is 100 ± 10 m.

Further, an array of elements can be used on the **14.6** **0.0** surface of a prism. This is shown in the next figure. Light from a laser source is focused by a lens onto the **14.6** **0.0** surface. A beam splitter reflects some light from the laser source. The rest of the light passes through the lens and is reflected by a mirror. The reflected light from the mirror is collected by a lens and focused onto a photodetector.

The main advantage of optical system of the type which has refractive optical elements is that, due to the step surface, there is no cavity loss, i.e., the light is not reflected in the optical system. The longer the wavelength, the larger is the step and the refractive index at the innermost position, the larger the ray effective diameter of the entrance surface becomes. Further, there is a problem that, as the angle of view increases, the ray effective diameter is increased and the entrance surface increases correspondingly.

... a central bearing of the
4,265.510 have a common feature
of about .4.00. Hence, the
very difficult in getting the -0.1

The photographic optical systems having a zooming function discussed in U.S. Patent Nos. 4,620,010 and 4,626,115, for the most part, consist of a large number of constituent parts such as mirrors and lens elements, or forming an arrangement to obtain sufficient optical performance; therefore, it is necessary to set all the optical parts in relative positions one another with high accuracy.

Finally, note that the selecting mirror, which is positioned at 0.07216 positive position coordinates, gives a $\frac{1}{2}$ magnification of each image.

It should also be noted that the conventional reflecting-type photographic optical systems are adapted for application to the so-called telephone-type lens systems as this type has a long focal length and a small field angle. To attain a hyperchromatic optical system which necessitates the field angles of from 10° to 20°, the standard lens to the wide-angle lens because an increasing number of reflecting surfaces for correcting aberrations is required to use the paraxial rays to be considered to even higher precision, accuracy and assembled with even a severer tolerance. Therefore, the production cost has to be paid. Otherwise, the size of the entire system tends to increase greatly.

also, the observing optical system is disclosed in the above U.S. Patent No. 4,771,214 and Japanese Laid-Open Patent Application No. 5-150971 to the present inventor, in order to produce the best system. It is such that the information display is positioned in front of the observer's eye, and it is conducted with high efficiency to the pupil of the observer. Another chief aim is to change the direction of light advantageously. Concerning the positive use of the curved-shaped lens, in order to correct aberrations, therefore, no spherical lenses are directly disclosed.

Also, the optical systems, for photo pickup disclosed in the above Japanese Laid-Open Patent Applications nos. Hei 5-127441 and Hei 6-138001 each limit its use to a detecting optical system. Therefore, these systems are unable to satisfy the imaging performance for photographic optical systems and particularly image pickup apparatus using a CCD or like area type image sensor.

BRIEF SUMMARY OF THE INVENTION 4.00 -4.00 -0.1 4.00

(VERTICAL ANGLE OF VIEW, HORIZONTAL ANGLE OF VIEW)

FIG. 39

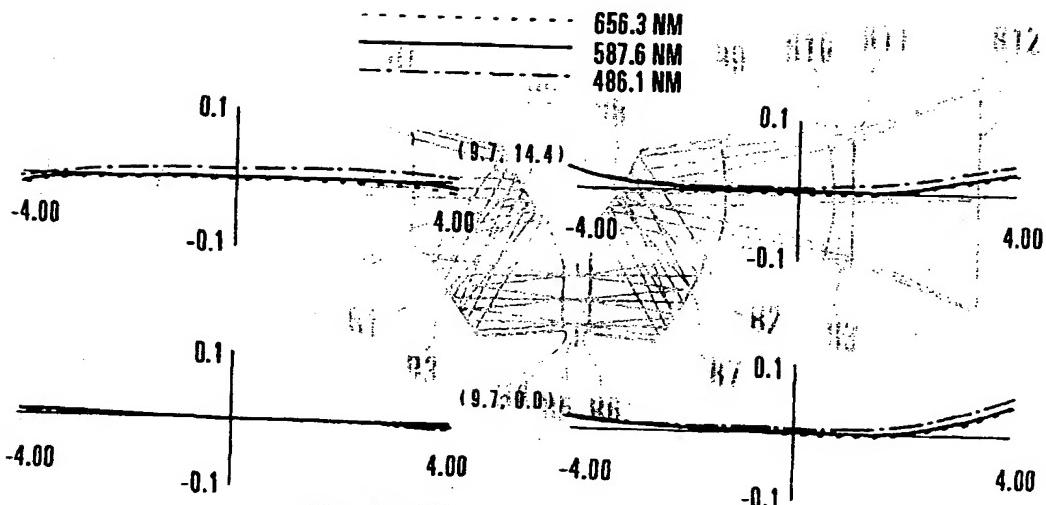


FIG. 35

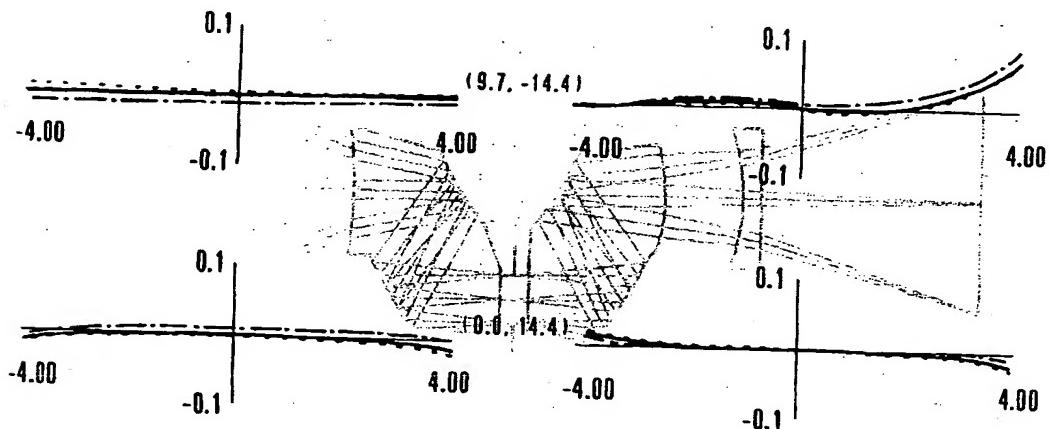
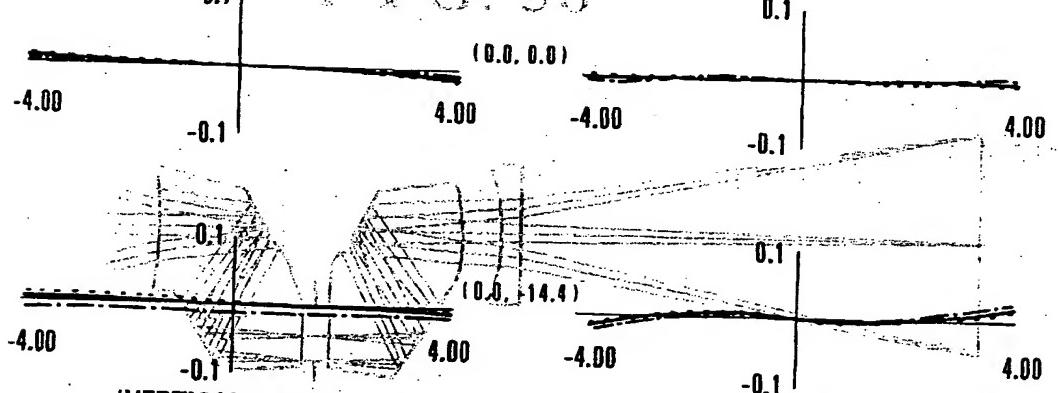


FIG. 36



(VERTICAL ANGLE OF VIEW, HORIZONTAL ANGLE OF VIEW)

Fig. 1 shows a schematic diagram of the embodiment 2 of the zooming system according to the invention, said system being shown in the wide-angle end.

Fig. 2 shows graphs of the lateral aberrations of the embodiment 2 in the wide-angle end.

Fig. 3 shows graphs of the lateral aberrations of the embodiment 2 in the middle position.

Fig. 4 shows a schematic diagram of the embodiment 2 in the telephoto end.

Fig. 5 shows sectional views of an embodiment 3 of the zooming system according to the invention, said system being shown in the wide-angle end.

Fig. 6 shows graphs of the lateral aberrations of the embodiment 3 in the wide-angle end.

Fig. 7 shows graphs of the lateral aberrations of the embodiment 3 in the middle position.

Fig. 8 shows graphs of the lateral aberrations of the embodiment 3 in the telephoto end.

Fig. 9 shows graphs of the lateral aberrations of the embodiment 3 in the wide-angle end.

Fig. 10 shows graphs of the lateral aberrations of the embodiment 3 in the middle position.

Fig. 11 shows graphs of the lateral aberrations of the embodiment 3 in the telephoto end.

Fig. 12 shows graphs of the lateral aberrations of the embodiment 3 in the wide-angle end.

Fig. 13 shows graphs of the lateral aberrations of the embodiment 3 in the middle position.

Fig. 14 shows graphs of the lateral aberrations of the embodiment 3 in the telephoto end.

Fig. 15 shows a schematic diagram of the basic configuration of the Cassegrain-type reflecting telescope.

Fig. 16 is a diagram for explaining a field method of leading the shadow by letting the optical ray away from the principal axis in the corner optical system.

FIG. 41

Fig. 17 is a diagram for explaining a field method of leading the shadow by letting the optical ray away from the principal axis in the main optical system.

Fig. 18 is a schematic diagram of the conventional zoom optical system using lenses.

Fig. 19 is a diagram of an alternative embodiment of the zoom optical system having its own lens surface.

Fig. 20 is a diagram of another alternative embodiment of the zoom optical system having its own lens surface.

Fig. 21 is a schematic diagram of the basic design of an embodiment 4 of the zooming system according to the invention.

Fig. 22 is a sectional view of the embodiment 4 in the wide-angle end.

Fig. 23 is a perspective view of the last optical element of the embodiment 4.

Fig. 24 is a diagram for explaining a field method of leading the shadow by letting the optical ray away from the principal axis in the main optical system.

Fig. 25 is a diagram for explaining a field method of leading the shadow by letting the optical ray away from the principal axis in the main optical system.

Fig. 26 is a schematic diagram of the basic design of an embodiment 5 of the zooming system according to the invention.

Fig. 27 is a diagram for explaining a field method of leading the shadow by letting the optical ray away from the principal axis in the main optical system.

Fig. 28 is a schematic diagram of the basic design of an embodiment 6 of the zooming system according to the invention.

Fig. 29 is a diagram for explaining a field method of leading the shadow by letting the optical ray away from the principal axis in the main optical system.

Fig. 30 is a schematic diagram of the basic design of an embodiment 7 of the zooming system according to the invention.

Fig. 31 is a diagram for explaining a field method of leading the shadow by letting the optical ray away from the principal axis in the main optical system.

Fig. 32 is a schematic diagram of the basic design of an embodiment 8 of the zooming system according to the invention.

Fig. 33 is a diagram for explaining a field method of leading the shadow by letting the optical ray away from the principal axis in the main optical system.

Fig. 34 is a schematic diagram of the basic design of an embodiment 9 of the zooming system according to the invention.

Fig. 35 is a diagram for explaining a field method of leading the shadow by letting the optical ray away from the principal axis in the main optical system.

Fig. 36 is a schematic diagram of the basic design of an embodiment 10 of the zooming system according to the invention.

Fig. 37 is a diagram for explaining a field method of leading the shadow by letting the optical ray away from the principal axis in the main optical system.

Fig. 38 is a schematic diagram of the basic design of an embodiment 11 of the zooming system according to the invention.

Fig. 39 is a diagram for explaining a field method of leading the shadow by letting the optical ray away from the principal axis in the main optical system.

Fig. 40 is a schematic diagram of the basic design of an embodiment 12 of the zooming system according to the invention.

Fig. 41 is a diagram for explaining a field method of leading the shadow by letting the optical ray away from the principal axis in the main optical system.

FIG. 42

Fig. 42 is a sectional view of the region of the embodiment 2 in the wide-angle end.

Fig. 43 shows graphs of the lateral aberrations of the embodiment 2 in the wide-angle end.

Fig. 44 shows graphs of the lateral aberrations of the embodiment 2 in the middle position.

Fig. 45 shows graphs of the lateral aberrations of the embodiment 2 in the telephoto end.

Fig. 46 is a schematic diagram of the basic design of an embodiment 3 of the zooming system according to the invention.

Fig. 47 is a diagram for explaining a field method of leading the shadow by letting the optical ray away from the principal axis in the main optical system.

Fig. 48 is a schematic diagram of the basic design of an embodiment 4 of the zooming system according to the invention.

Fig. 49 is a diagram for explaining a field method of leading the shadow by letting the optical ray away from the principal axis in the main optical system.

Fig. 50 is a schematic diagram of the basic design of an embodiment 5 of the zooming system according to the invention.

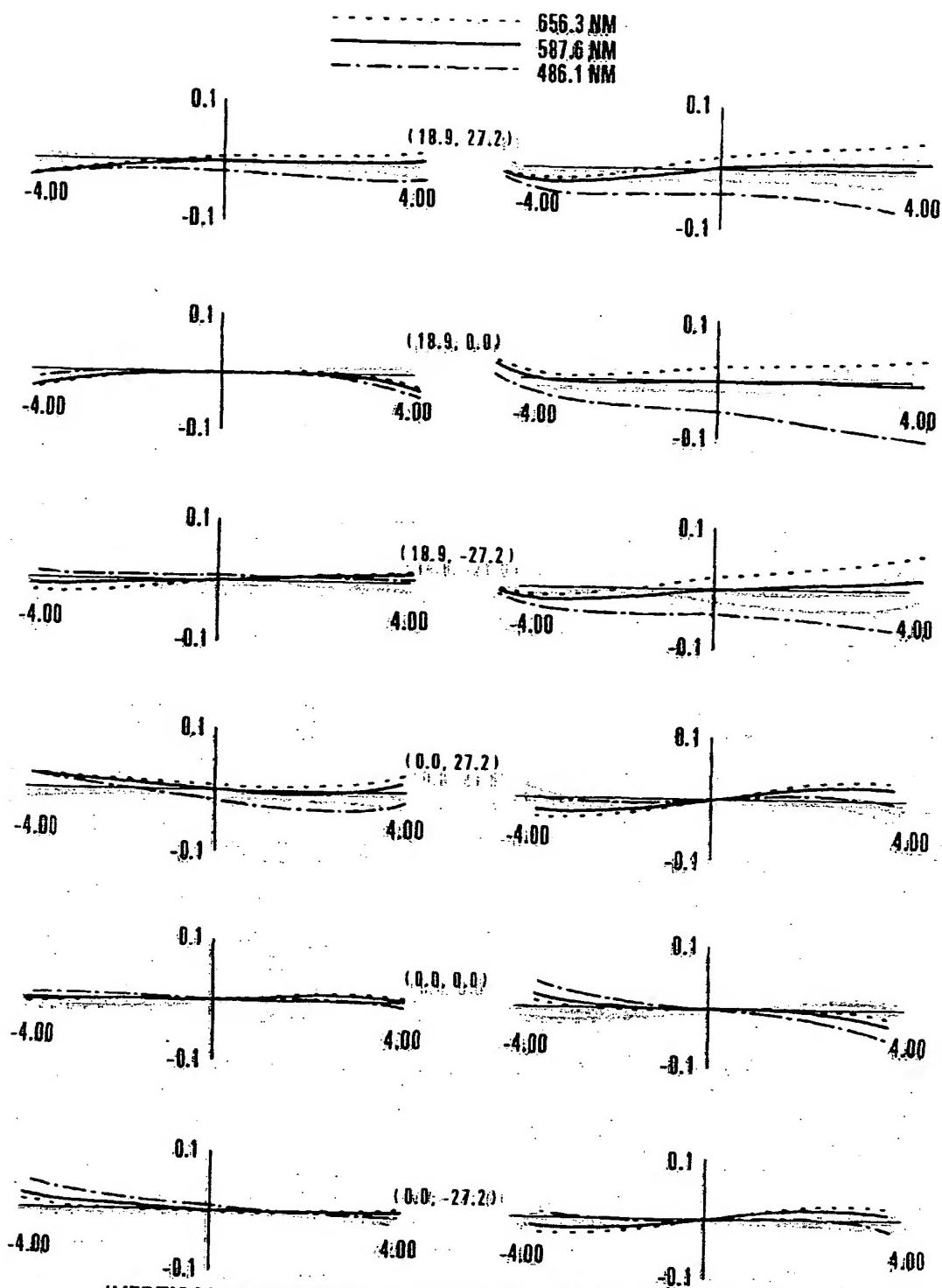
Fig. 51 is a diagram for explaining a field method of leading the shadow by letting the optical ray away from the principal axis in the main optical system.

DETAILED DESCRIPTION OF THE INVENTION

Before describing the embodiment of the zooming system, the way of expressing the various dimensions of the structure and the various features of all the components are described below.

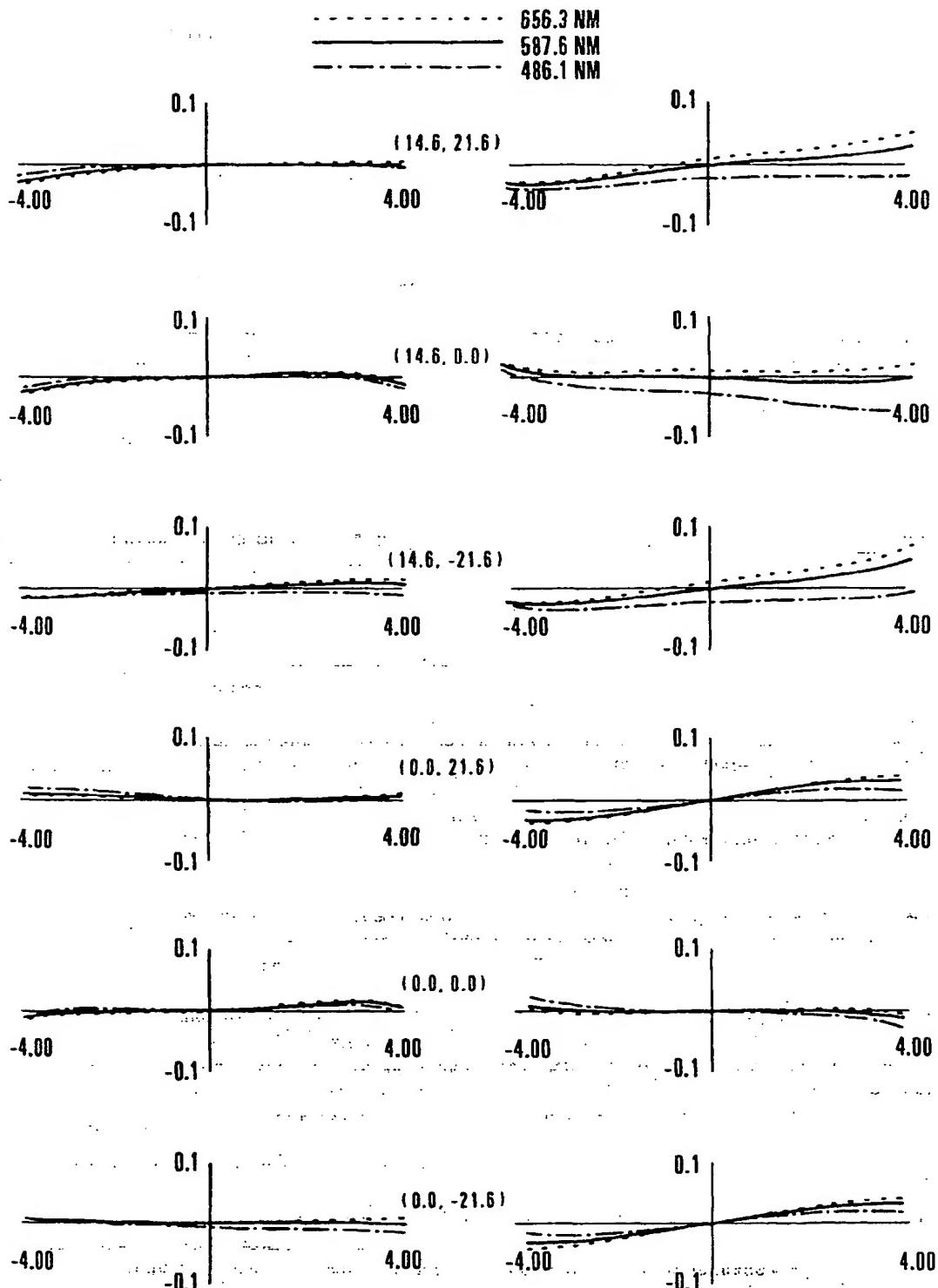
Fig. 5 is a diagram taken to explain the coordinate system by which to obtain the design parameters for the optical system of the invention. In the embodiments of the invention, the surfaces are numbered consecutively along a ray of

FIG. 43



(VERTICAL ANGLE OF VIEW, HORIZONTAL ANGLE OF VIEW)

FIG. 44



(VERTICAL ANGLE OF VIEW, HORIZONTAL ANGLE OF VIEW)

FIG. 45 (a)

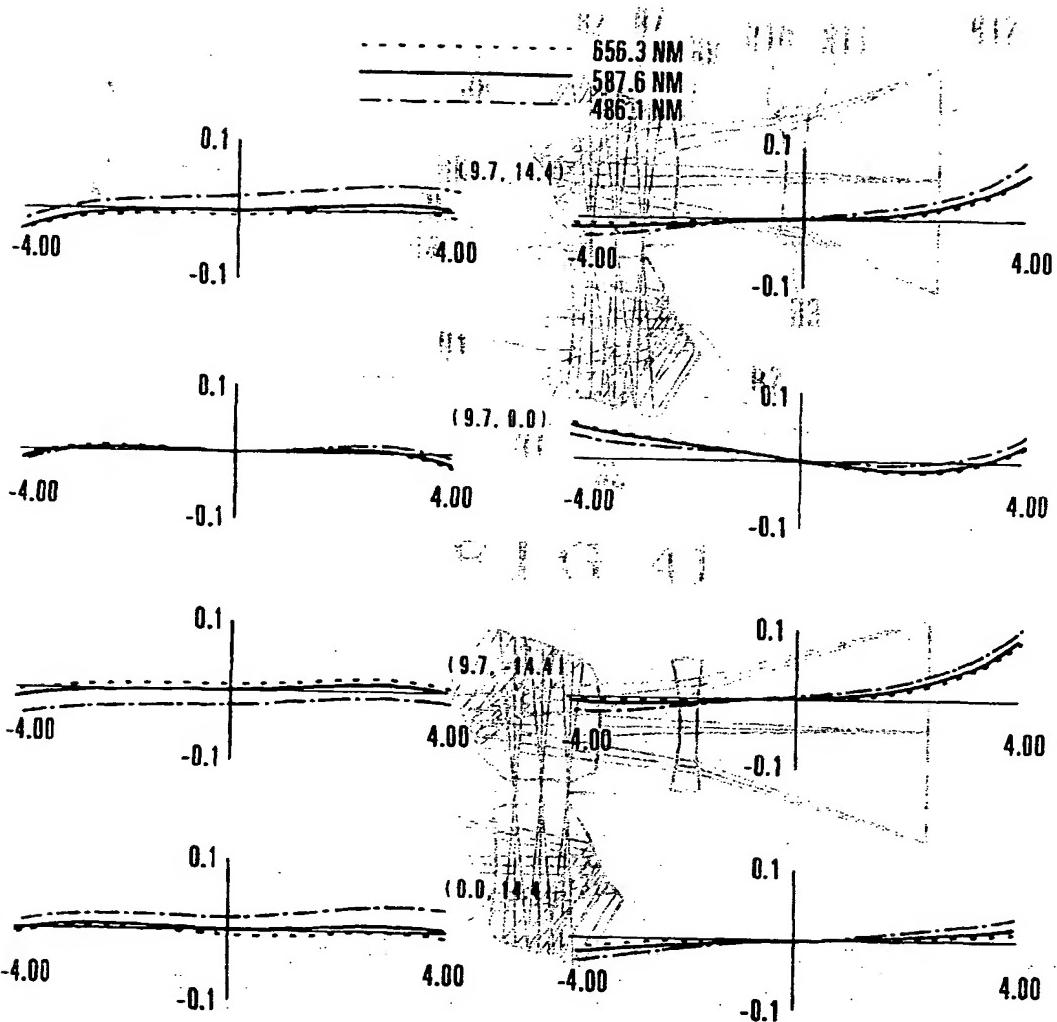
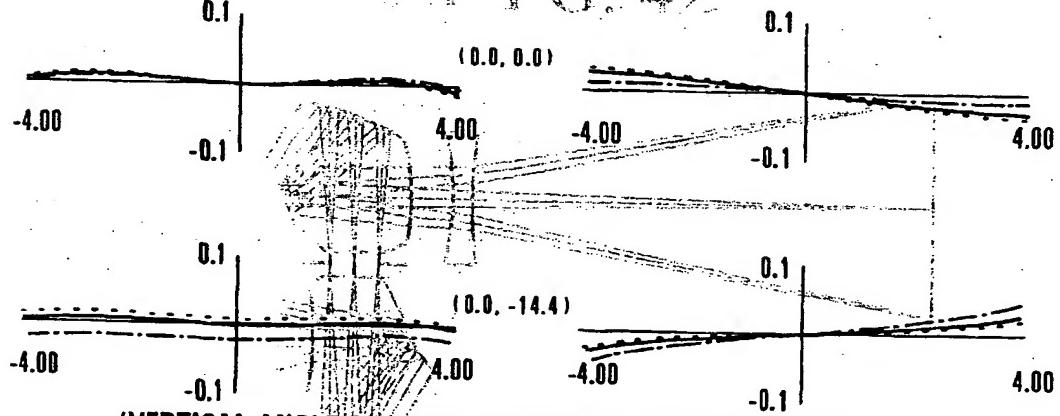
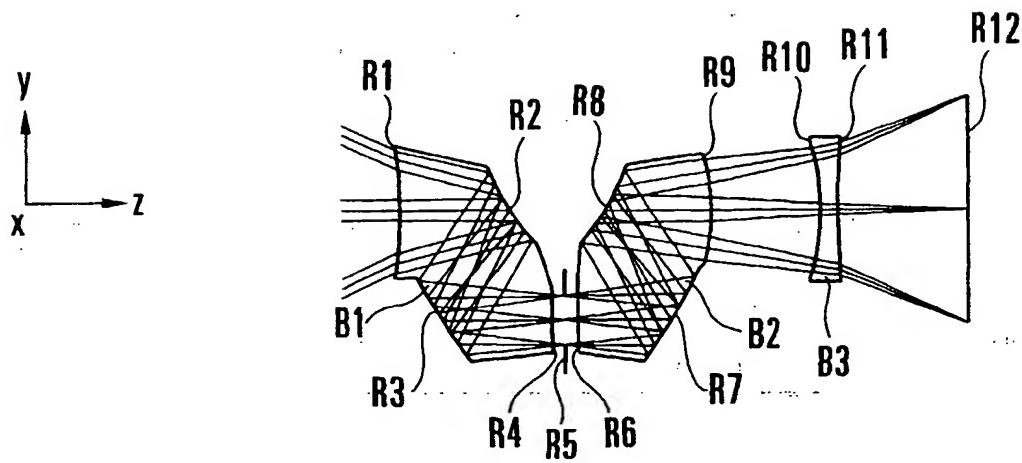


FIG. 42

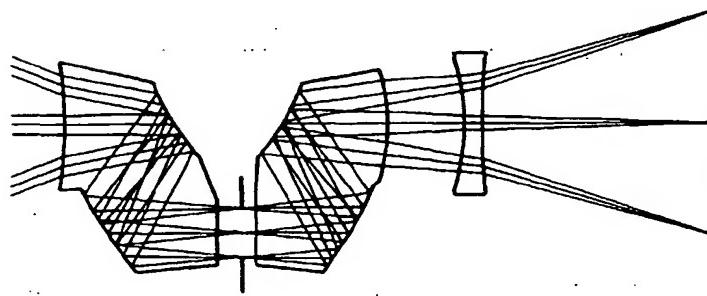


(VERTICAL ANGLE OF VIEW, HORIZONTAL ANGLE OF VIEW)

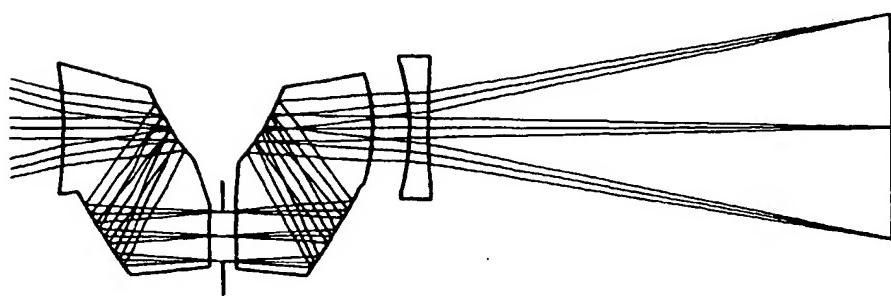
F I G. 46



F I G. 47

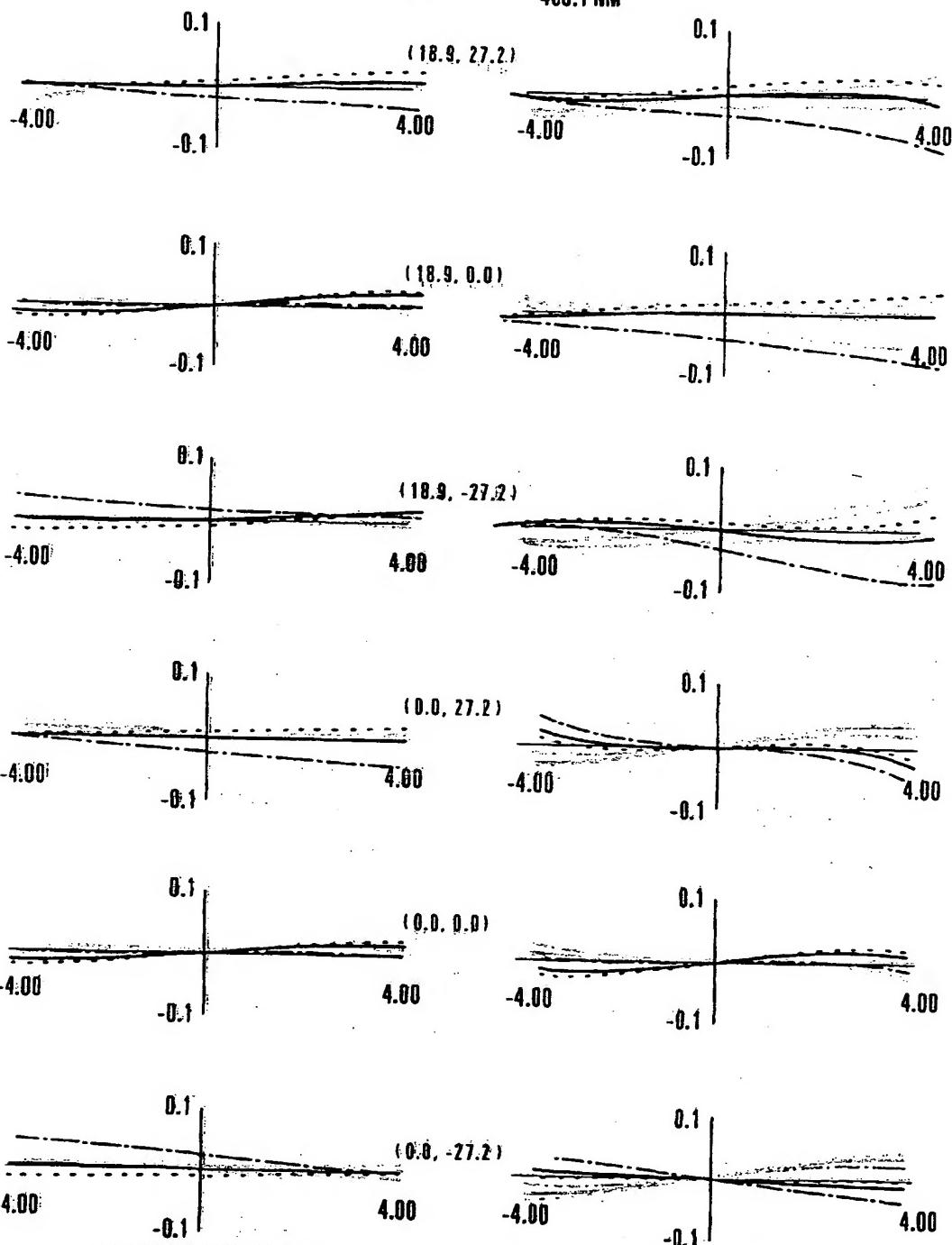


F I G. 48



F H G. 494

656.3 NM
587.6 NM
486.1 NM



(VERTICAL ANGLE OF VIEW, HORIZONTAL ANGLE OF VIEW)

F I G. 50

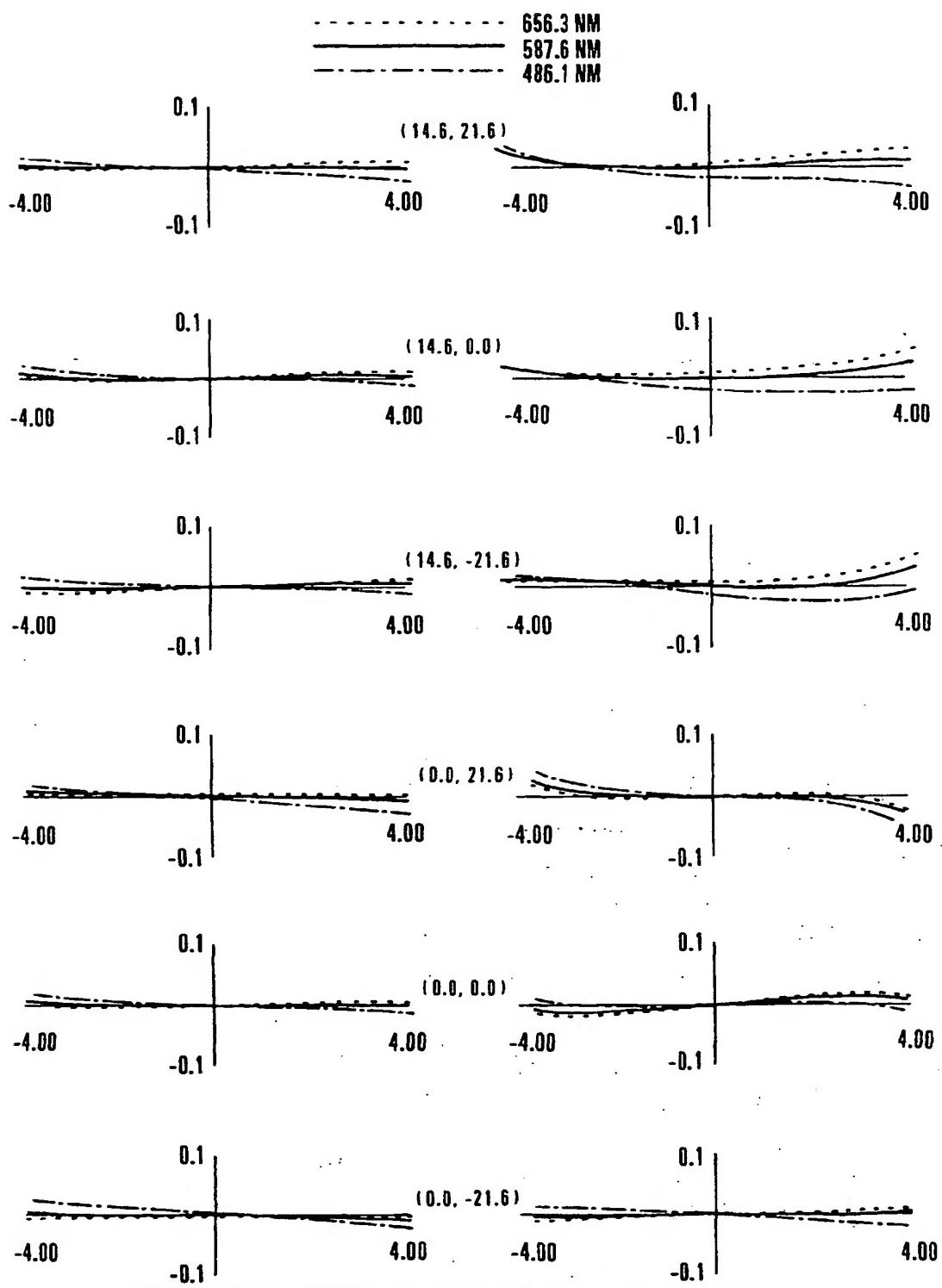


FIG. 51

656.3 NM
587.6 NM
486.1 NM

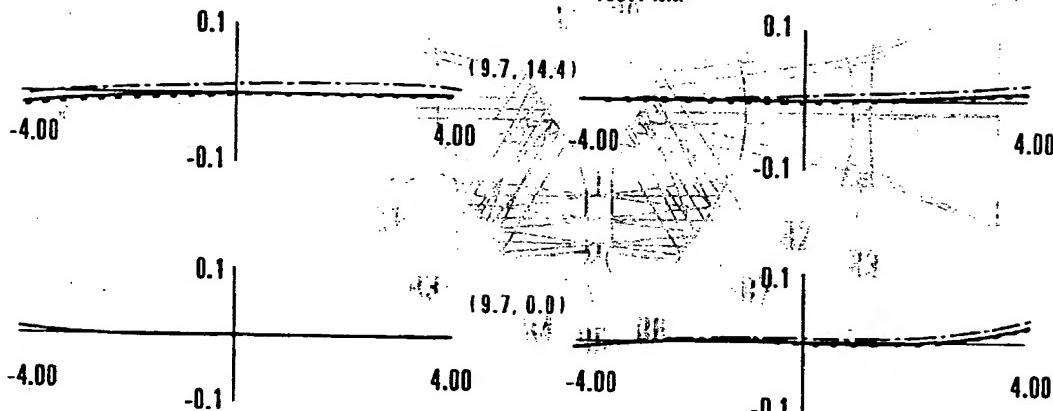


FIG. 51-47

(9.7, -14.4)

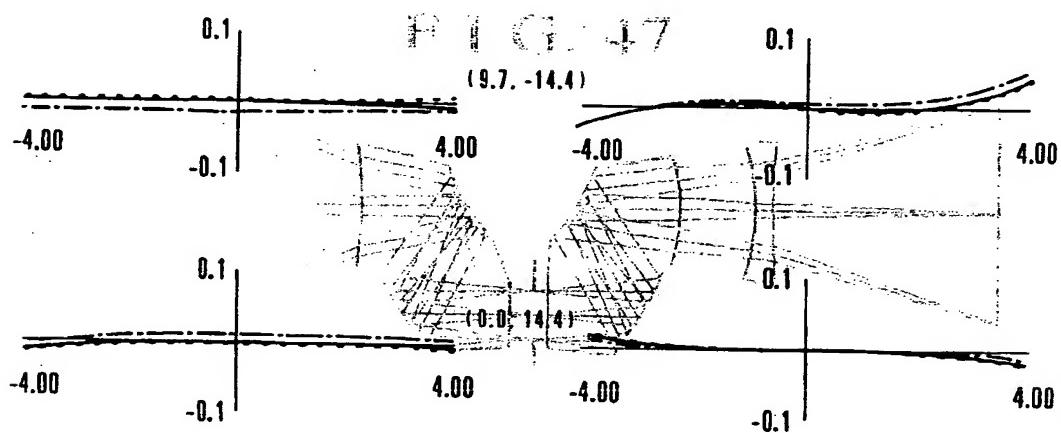
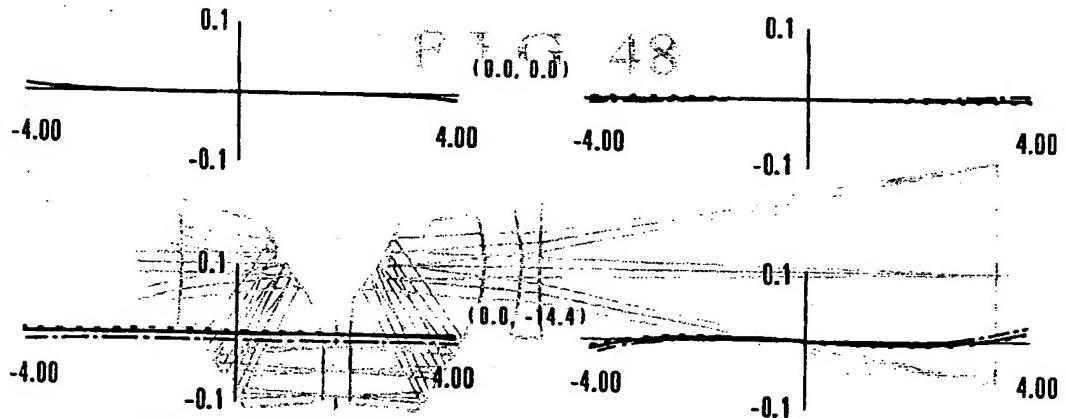


FIG. 51-48

(0.0, 0.0)



(VERTICAL ANGLE OF VIEW, HORIZONTAL ANGLE OF VIEW)



(12)

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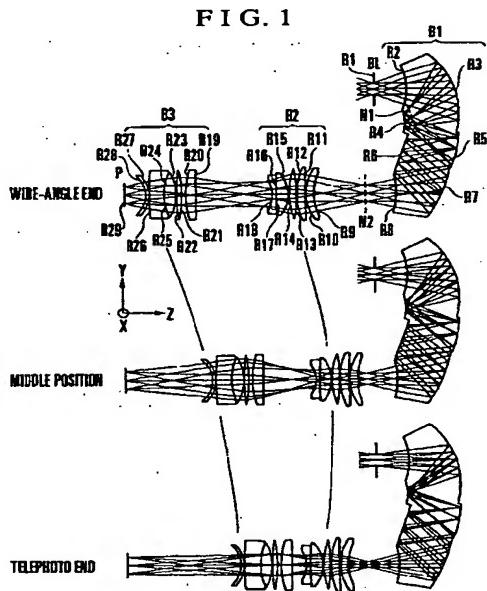
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(54) Zoom lens

(57) A zoom optical system comprises a plurality of optical elements. The plurality of optical elements include a first optical element having two refracting surfaces and a plurality of reflecting surfaces formed in a transparent body, being arranged such that a light beam enters an inside of the transparent body from one of the two refracting surfaces and, after being successively reflected from the plurality of reflecting surfaces, exits from the other of the two refracting surfaces, and/or a second optical element having a plurality of surface mirrors integrally formed and decentered relative to one another, being arranged such that an incident light beam exits therefrom after being successively reflected from reflecting surfaces of the plurality of surface mirrors; and a third optical element composed of a plurality of coaxial refracting surfaces. In the zoom optical system, an image of an object is formed through the plurality of optical elements, and zooming is effected by varying relative positions of at least two optical elements of the plurality of optical elements.





**European Patent
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EUROPEAN SEARCH REPORT

Application Number

EP 97 10 2430

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